Elementary, Economic Experiments in Physics

by Reginald F. Melton

III. student guide

Published by
Centre for Educational Development Overseas
Tavistock House South
Tavistock Square
London WC1H 9LL.

Student Guide

to

ELEMENTARY, ECONOMIC EXPERIMENTS IN PHYSICS

by

REGINALD F. MELTON

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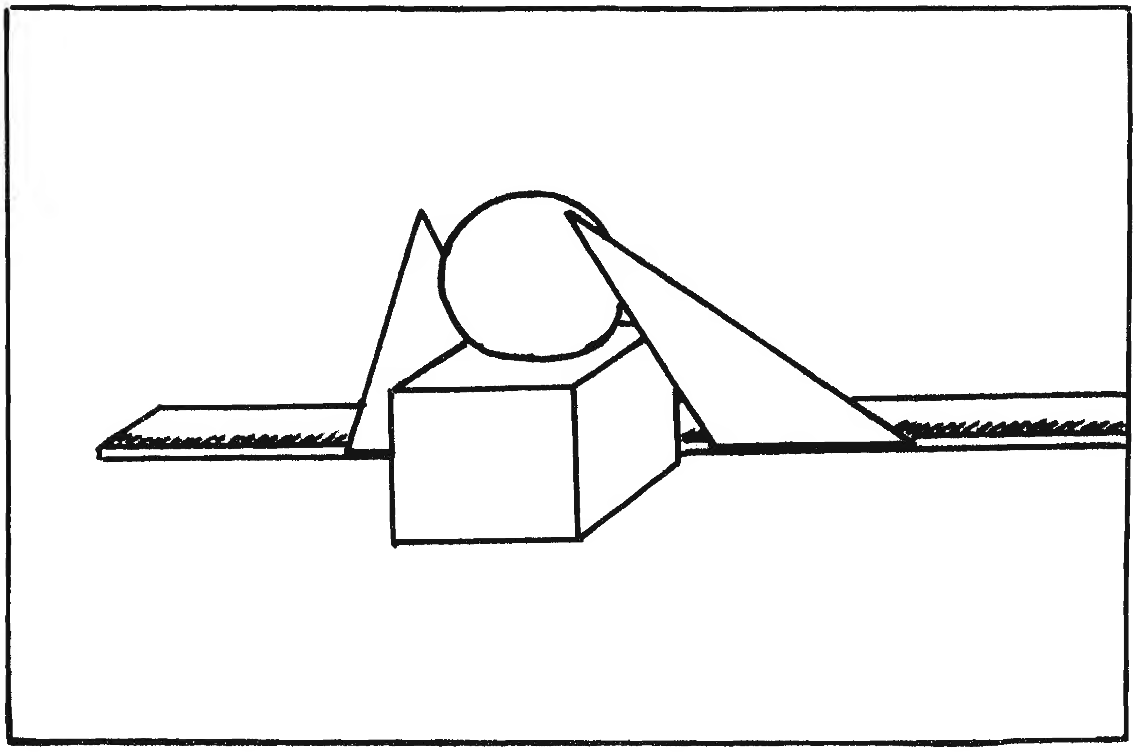


Qu.	Apparatus	Item No.
1	Ping Pong Ball	
2	Wooden Cubes, 4 x 4 x 4 cm (approx.)	
1	Meter Rule	
2	Set Squares, 10 x 17 x 20 cms (approx.)	

Activities

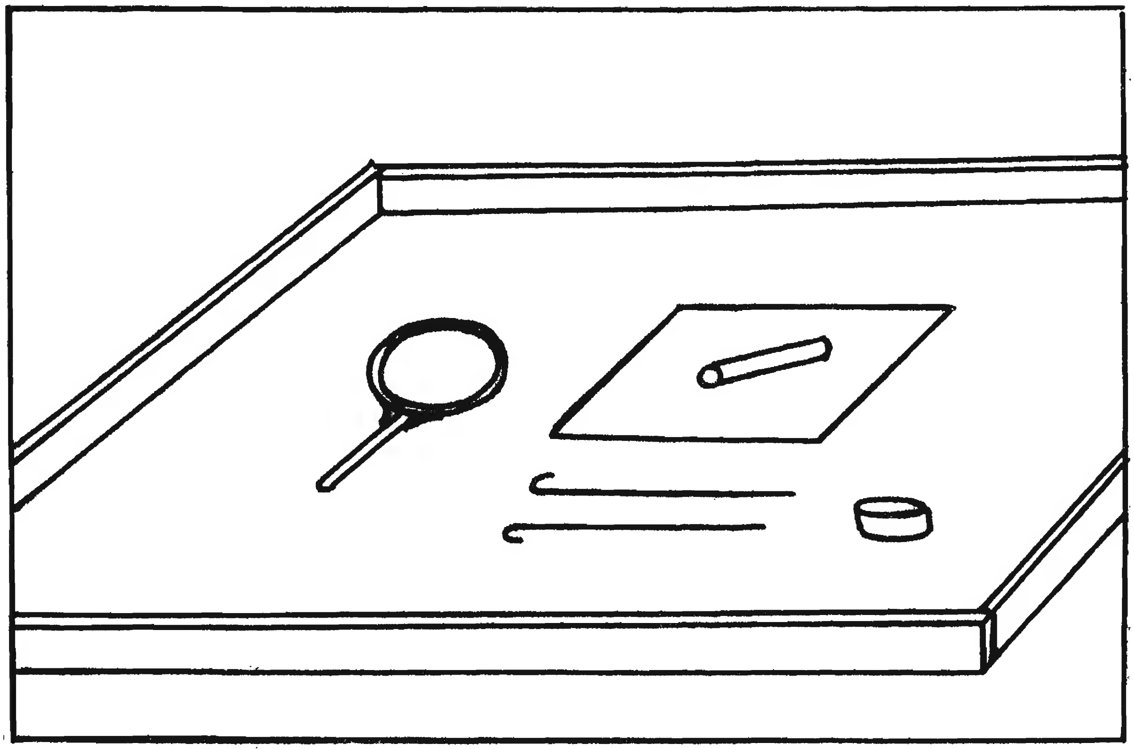
(i) Take your ruler, and measure the diameter of the ping pong ball as accurately as possible. Compare your result with your partner. How reliable do you think your results are? You are provided also with two wooden cubes. Can you improve the accuracy of your measurements by using these? Finally place the ball on top of one of the cubes. If you are not allowed to remove the ball from the block how would you try to measure its diameter accurately? Would a set square be of any assistance?

(ii) Try measuring the width of the room as accurately as possible. Do you hesitate to express your answer to the nearest millimeter? Compare your results with those of other students. How accurately should you indicate your result?

(iii) Can you measure the thickness of a sheet of paper fairly accurately? If you measure the thickness of fifty sheets of paper placed one on top of the other does this help to determine the thickness of one item alone more accurately?

1.12 Thickness of Oil Films

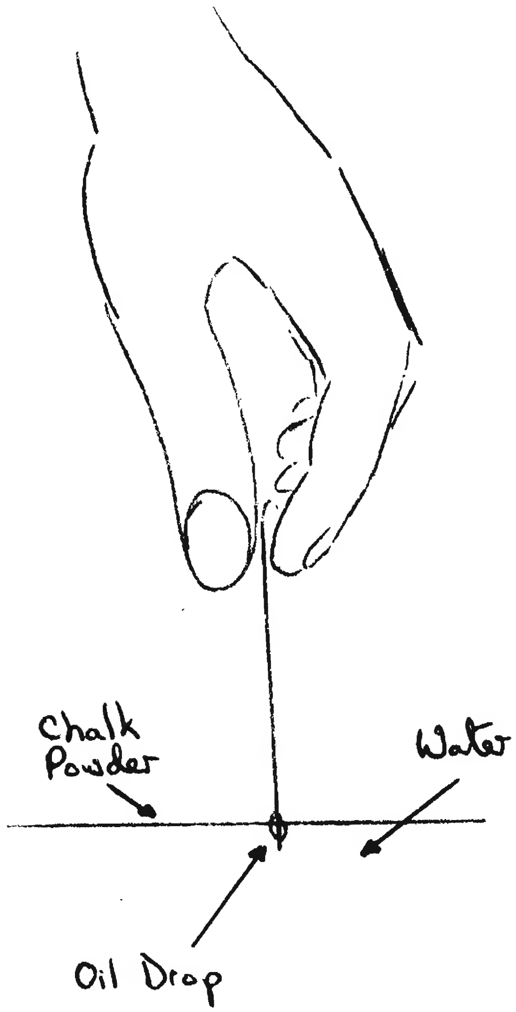
Apparatus Required



Qu.	Apparatus	Item No.
1	Ripple Tank Base	3.10/01
1	Sheet of Sandpaper (00)	
2	Steel Wires (No. 30, 7 cms long)	
1	Hand Lens	
1	Olive Oil Container (Use bottle top as container)	
1	Stick of Chalk	
1	Meter Rule	

Activities

(i) Use the ripple tank base as a water container. Make sure it is thoroughly clean by washing with soap and water. Do the same with the small lengths of wire, and make sure your hands are also clean. Rinse everything thoroughly in water. Fill the tank to a depth of 2 to 3 cms with water, and cover the surface of the water with a very fine layer of chalk dust by rubbing a piece of chalk on the sandpaper.

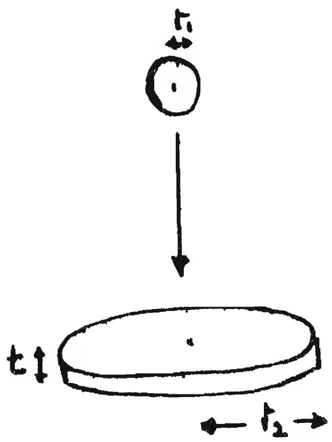


Dip the steel wire into the olive oil, and by means of the wire transfer a drop of the oil to the surface of the water. Observe the chalk on the surface of the water. What happens?

Repowder the surface of the water with chalk, and repeat the experiment,in this case using water contaminated with one drop of oil. Is there any difference in the behavior observed?

Finally add fairly large drops of oil (simply pour from container) successively to the water without further rechalking of the surface. Watch what happens to the drops once they touch the surface of the water.

(ii) If it is true that a drop of oil spreads out uniformly over a clean (uncontaminated) water surface it should be possible to measure the thickness of the oil film on the water by simply comparing its volume with that of the original drop. Thus if the original oil drop has a radius of r_1 cms its volume must be $(4/3)\pi r_1^3$ ccs. If the same oil drop spreads over the water to form a film of thickness t cms and radius r_2 cms then the volume of the film must be $\pi r_2^2 t$ ccs.



It follows that:

$$4/3\ \pi r_1^3 = \pi r_2^2 t$$

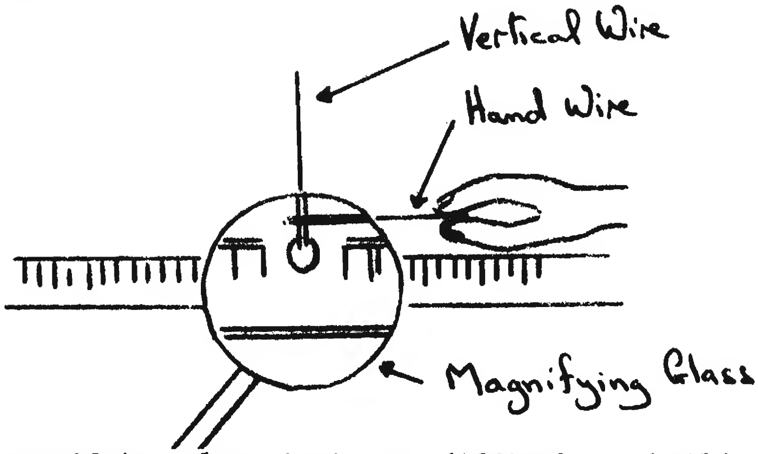
and hence that:

$$t = \frac{4\ r_1^3}{3\ r_2^2}\ \text{cms}$$

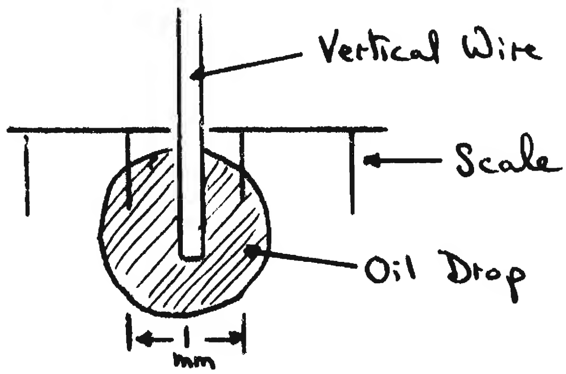
It is proposed that an oil drop of diameter 1 mm should be added to the surface of clean water, and the diameter of the resultant oil film noted. It should then be possible to determine the thickness of the newly formed film.

For this experiment the ripple tank, wires and hands are thoroughly cleaned with soap and water, all soap being removed by careful rinsing. Clean water is added to the tank, and the surface powdered with chalk in the usual way. The oil drop is created by means of two steel wires, one supported vertically, and the other held in the hand. The latter is dipped into the oil, and the small droplets picked up transferred to the vertical wire by direct contact. The

hand wire is then used to tease the small droplets down the vertical wire to form a larger droplet at the bottom. With the help of a millimetre



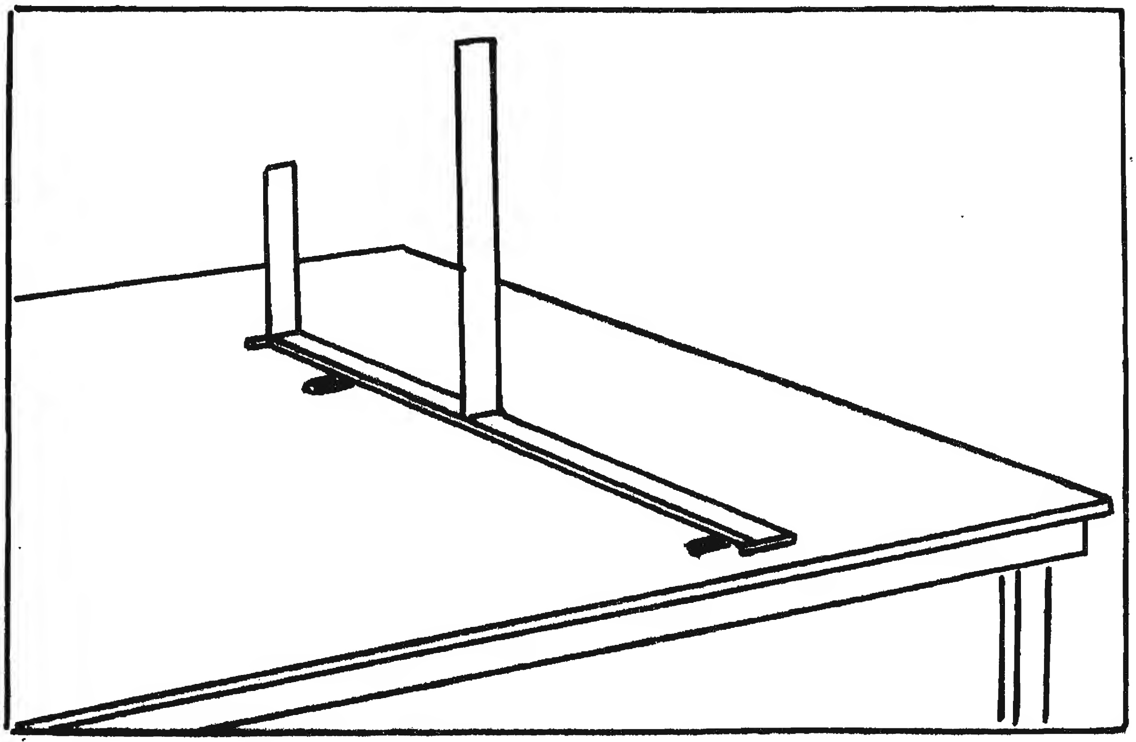
scale and a magnifying glass it is not difficult to build up an oil drop with a diameter of 1 mm. In fact the diameter of the oil drop should be made just a little bigger than 1 mm in order to compensate for the volume taken up by the wire itself.



Don't knock the drop off the wire into the water, but lower it gently into the water, and the oil will transfer automatically to the water surface. Measure the diameter of the film created on the water, and then calculate the thickness of the film.

1.13 Triangulation

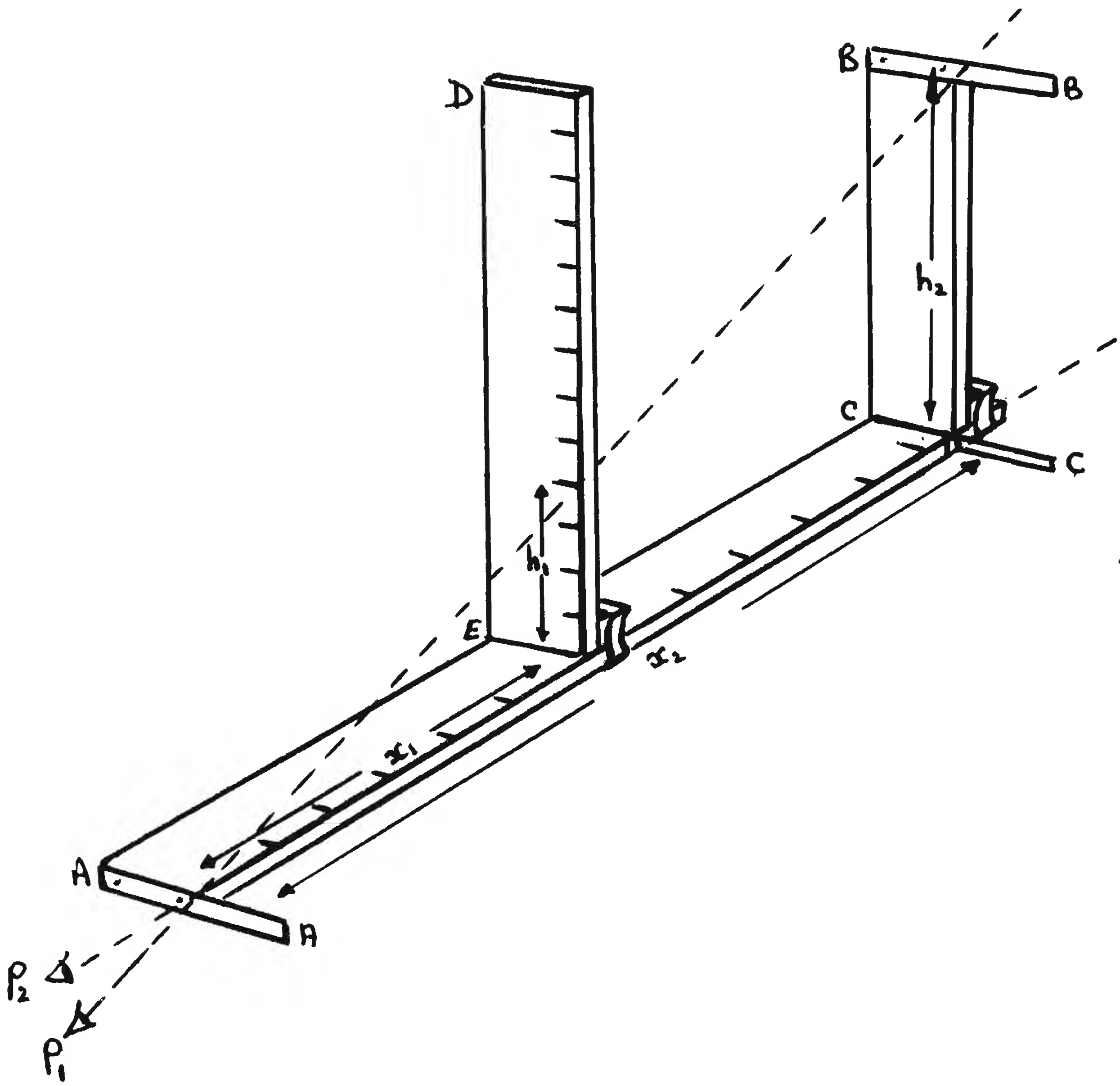
Apparatus Required



Qu.	Apparatus	Item No.
1	Triangulation Device	1.10/01
1	Meter Rule	

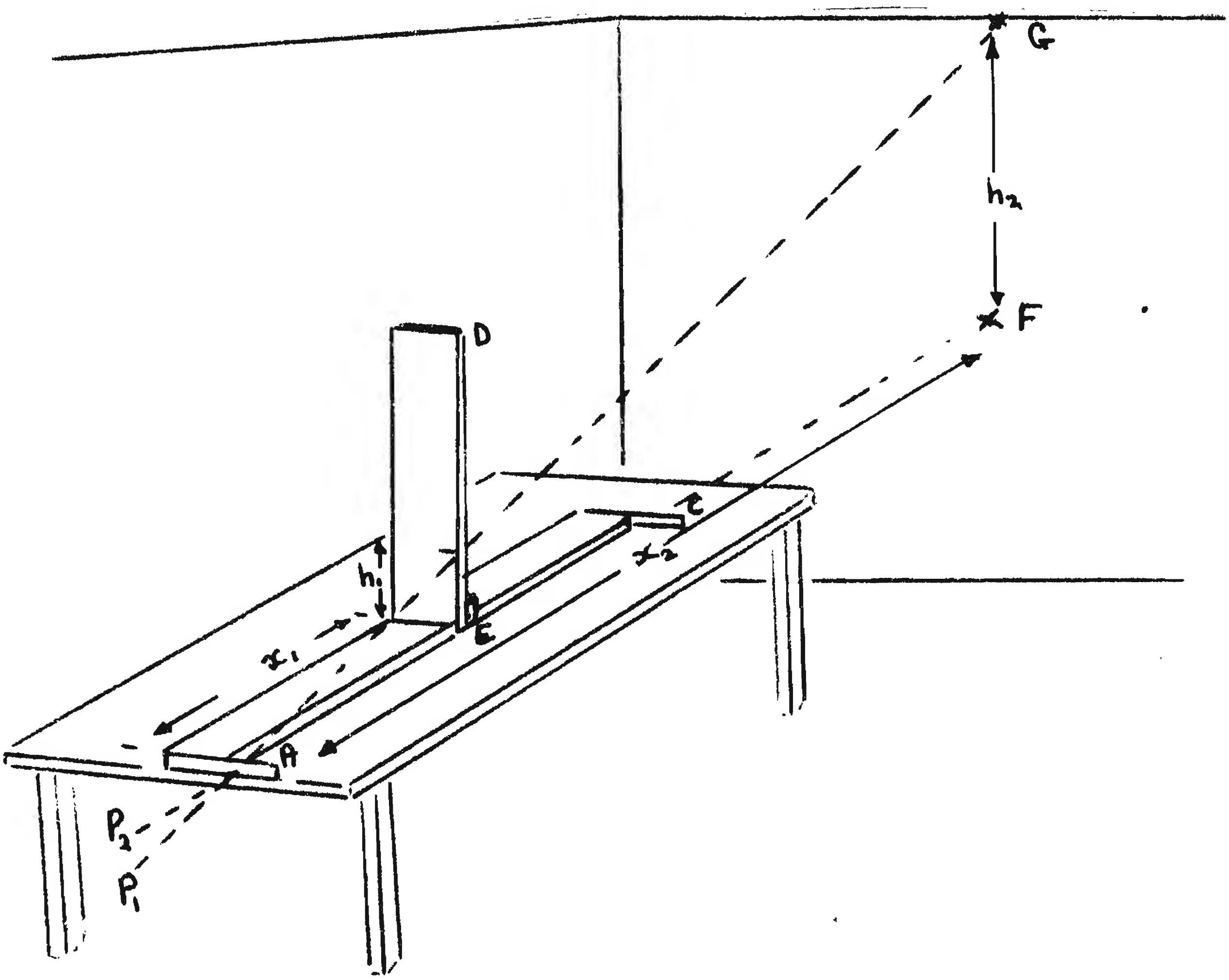
Activities

(i) It is just as important to be able to measure the size of unusually large objects as it is to measure unusually small ones. For example, how would you try to measure the height of a telegraph pole, a tree, or a mountain? You can't just take a ruler. Some system of triangulation must be used.



To understand this system take the triangulation apparatus, and place it on a horizontal surface. The upright BC is 10 cms high (h_2), and is set at the end of the horizontal beam AC. DE is a calibrated upright which can be moved backwards and forwards along AC. Place the upright DE a distance of 10 cms (x_1) from A, and then view the apparatus from position P_1 so that the horizontal bars of A and B appear to overlap. Note the height (h_1) marked off on DE by the horizontal bar A. Repeat the experiment with DE placed at 20, 30 and 40 cms from A. Do the results show any type of relationship between x_1, x_2, h_1 and h_2?

(ii) Now try to apply your result to measure other objects. Remove upright BC from the apparatus, and replace it by an upright of unknown height such as a wall. View the apparatus from position P_2 lining up the horizontal



bars A and C with a position on the wall which should be recorded as F. Then from position P_1 line up the horizontal bar A with the top of the wall G. By noting the distances x_1 and x_2 together with the height of the upright h_1 it should be possible to calculate the height h_2 of the wall from F to G. It is up to you to choose a convenient position for the upright DE and the distance from the wall to A. Determine the height of the wall from two different positions (e.g. such that AF equals 4 meters in the first experiment, and 5 meters in the second). How do the results compare?

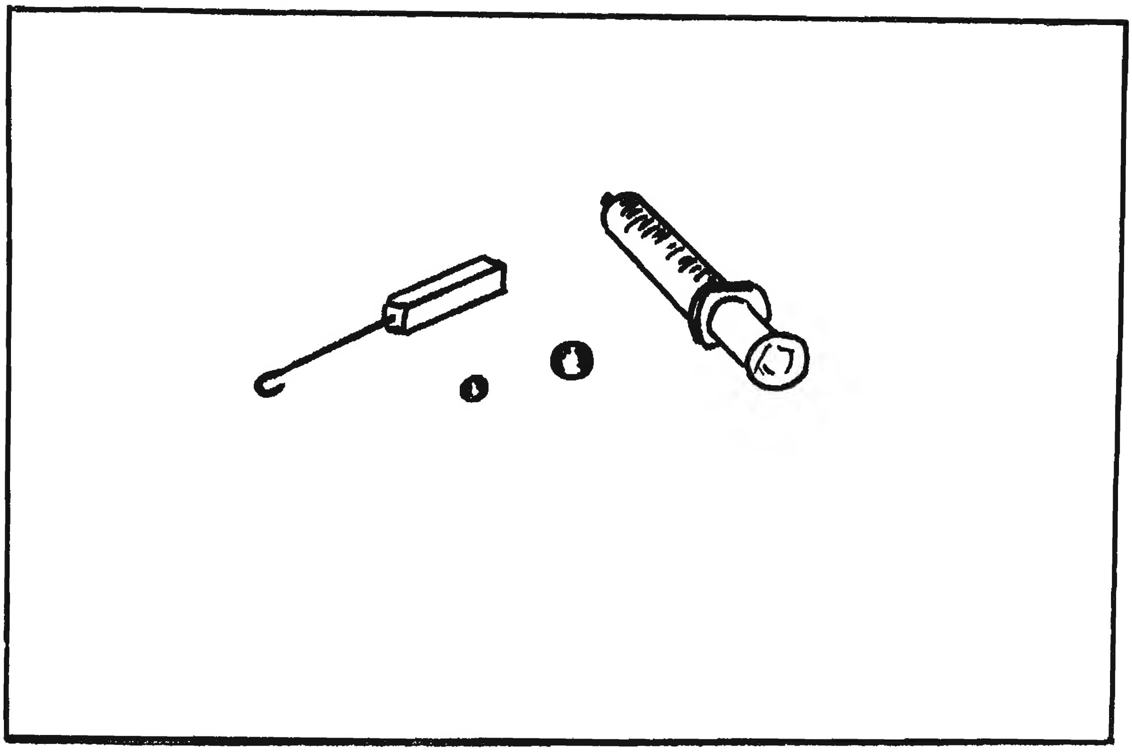
Had the above experiment been performed from two different positions as suggested, noting only the distance between the positions (1 meter in the above example) and not the actual distance from the wall in each case, it would still have been possible to determine the height of the wall. This involves a little mathematics, but you should be able to do it.

(iii) Try lying the apparatus on its side in order to measure the width of the classroom. Check your result afterwards with a meter rule.

You should now have no difficulty in seeing how you could measure the height of a tree, or a mountain, even if you do not know how far the tree or mountain is from your position. In fact this unknown distance can also be calculated from your observations.

1.14 Volume

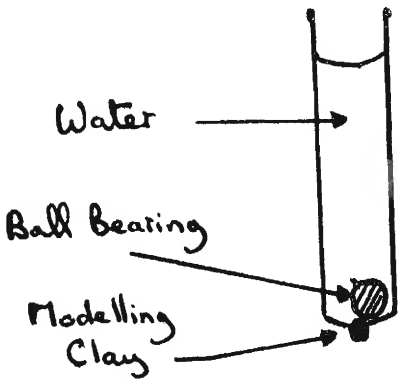
Apparatus Required



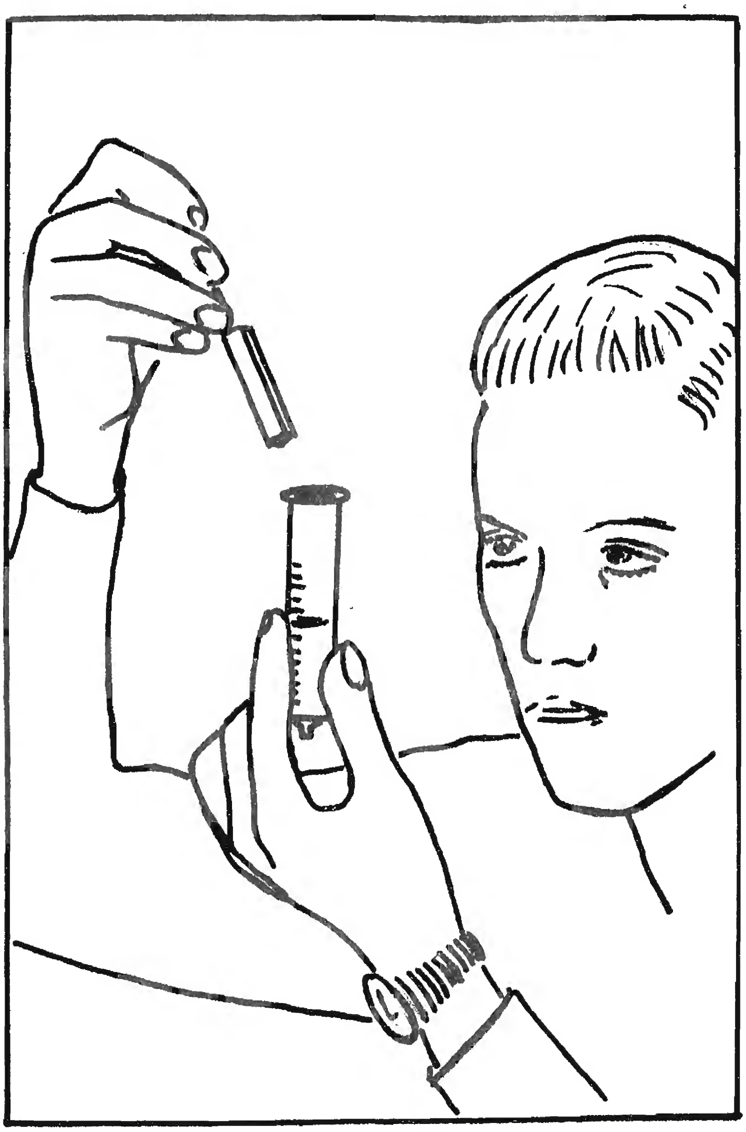
Qu.	Apparatus	Item No.
1	Steel Ball Bearing (Diam. 0.8 cm)	
1	Steel Ball Bearing (Diam. 1.2 cm)	
1	Displacement Block	1.10/02
1	Plastic Syringe (Minimum Capacity 10 ccs, and minimum diam. 1.5 cms)	

Activities

(*i*) Remove the plunger from a plastic syringe, and block off the end of the syringe with modelling clay. You now have a graduated cylinder.



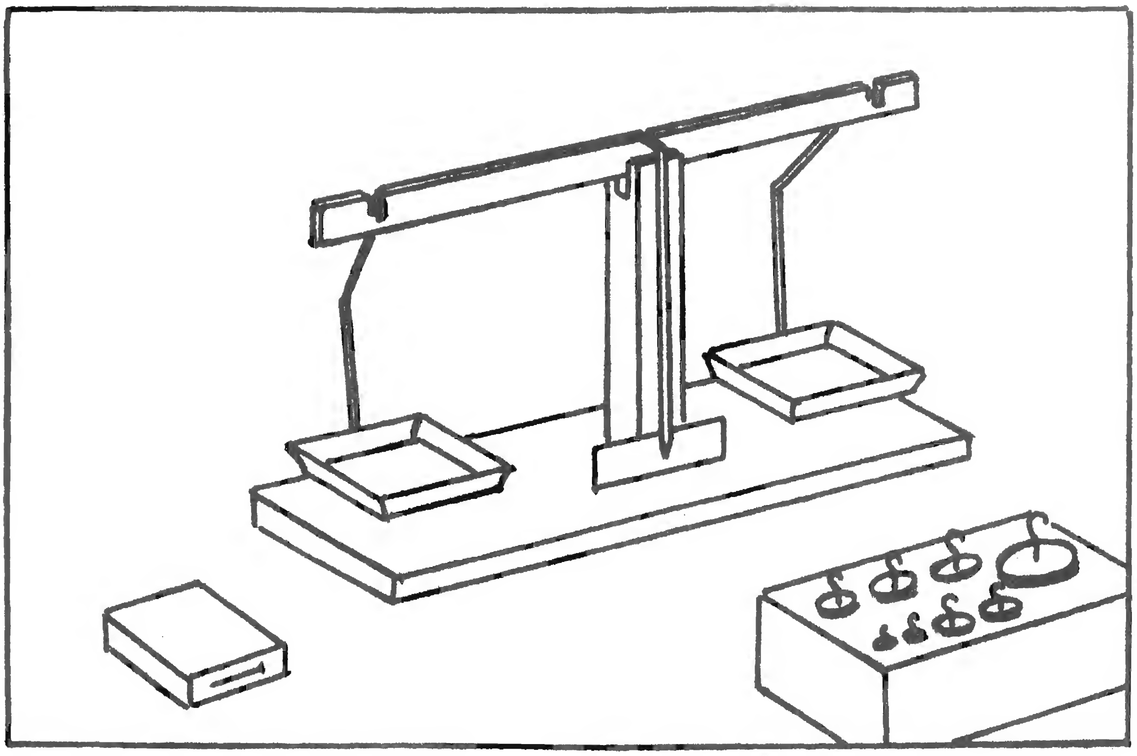
Partially fill the syringe with water, and note the surface level. Then take the two ball bearings supplied (0.8 and 1.2 cms in diameter respectively). Don't make any calculations, but try to guess their volumes. Then drop them gently (one and then the other) into the cylinder. Noting the new water level should indicate to you the volumes of the two spheres. Are you surprised? Do you believe the graduations on the cylinder? To check the reading take the displacement block, and lower it gently into the syringe, noting the new water level for each cubic centimeter of water displaced by the block. Do the graduations on the syringe conform with your observations?



1.20 MASS

1.21 The Simple Balance

Apparatus Required



Qu.	Apparatus	Item No.
1	Balance	1/20/01
1	Box of Weights	1/20/02
1	Modelling Clay	
1 box	Small Nails	
1	Cardboard Strip (10 x 2 cms)	
2	Elastic Bands	

Activities

(i) Take a pile of small nails and count out 30 of them as quickly as you can. Does it take long? If you were asked to count out 300 would you object? I'm sure you wouldn't like to sort out a large sack of nails into piles of 300 each. Maybe there is an easier way.

Take the simple balance provided and adjust the position of the small counterbalance until the balance beam is horizontal.

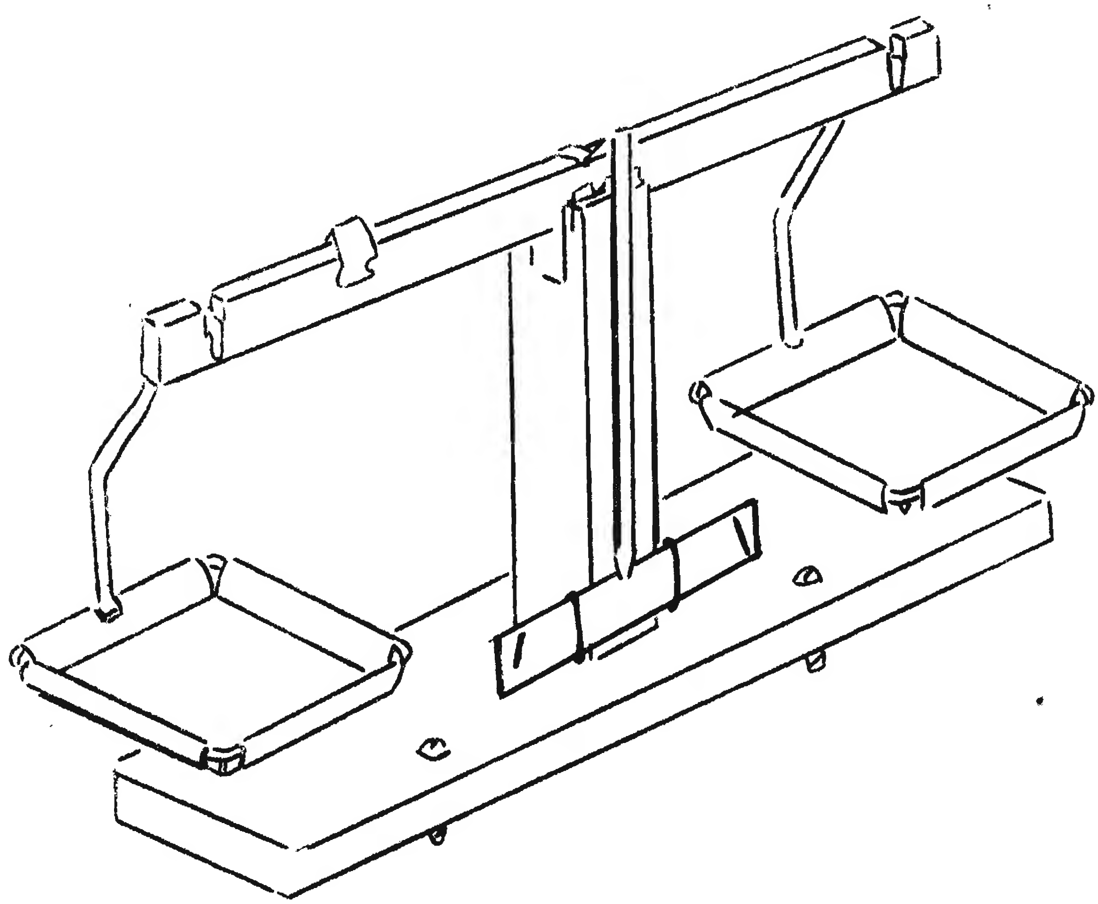
Now place your pile of nails (30)in one of the balance pans, and then in order to rebalance the apparatus add pieces of modelling clay (plasticene) to the other pan. When a balance has been obtained roll the pieces of the modelling clay into a ball, and mark with a number 1, and then replace it in the same pan. Now without counting out the nails can you actually produce another pile of 30? All you have to do is pour the nails from the pan, and pour in another pile sufficient to create a balance. When you have done this count the nails as a check. We say that we have the same mass of nails in each case. The piece of plasticene marked No. 1 is a useful unit for measuring out equal numbers of items, and we call it a unit mass.

It is very easy to choose a unit of mass. It might correspond to 30 nails, or a thousand grains of rice, or a hundred mongo beans. However, it is important that we should all mean the same thing when we talk about 1 unit mass of something. As a result units tend to be standardized. We still have 2 different major units of mass, the pound and the kilogram, but probably in the not too distant future the pound as a unit will disappear. Compare your own unit of mass with a kilogram mass, or more easily with a gram mass (1000 grms = 1 kilogram).

(ii) Provided with a series of 10 gram masses only, measure the mass of objects such as your pen, ruler or pencil to the nearest 10 grams.
Now let's see if you can weigh your pen to the nearest gram without additional small weights.

Take one of the objects you have already weighed to the nearest 10 grams, for example a pen, and let's say that its mass was somewhere between 10 and 20 grams. Create a counterpoise of modelling clay for the left pan so that

when a 10 gram mass is placed in the right pan the pointer approaches the extreme right of the horizontal scale on the balance while a 20 gram mass will cause the pointer to swing towards the extreme left of the scale. Place a long cardboard strip over the original scale, holding it in position with elastic bands. Mark the extreme positions of the pointer on the scale,

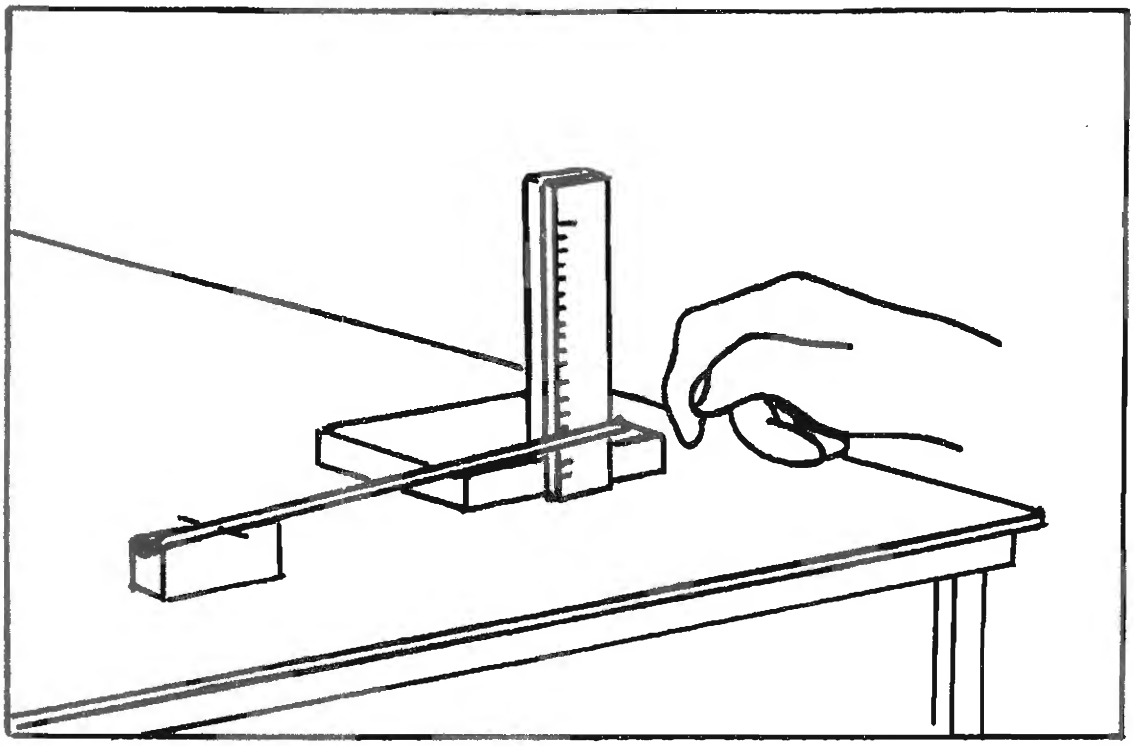


and then divide the intervening distance into 10 equal units. Now replace the mass in the right hand pan by the pen, and determine its mass from the new balance position of the pointer on the scale.

In order to check your results place two masses of 10 and 5 grams in the right hand pan, and observe the balance position on the scale. Can you indicate roughly how accurately you might have determined the mass of the pen?

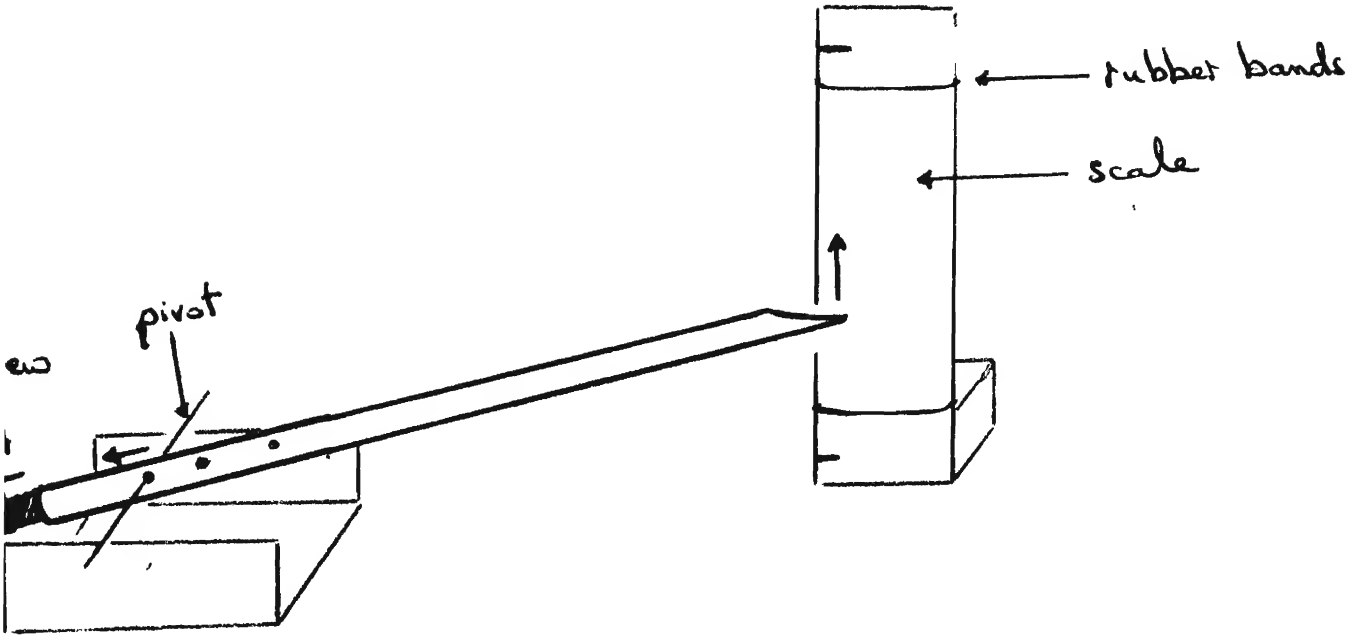
1.22 Microbalance

Apparatus Required



Qu.	Apparatus	Item No.
1	Microbalance and Scale	1.20/03

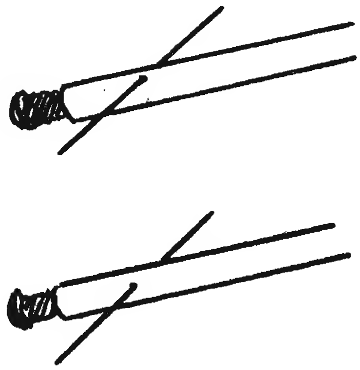
Activities



(i) Adjust the position of the needle pivot and adjustment screw until the straw points towards the top of the scale. Attach a strip of paper to the scale with rubber bands, and mark on it the upper position of the straw pointer.

To calibrate the balance take 10 sheets of paper, and cut them to 20 x 25 cms each. Weigh the newly cut sheets together on the ordinary balance. A simple calculation will give you the mass of each sheet, one square centimeter of each sheet and fractions of each square centimeter. Cut a square centimeter (or a fraction of this) from a single sheet and place it on the end of the straw balance. Taking note of the new balance position of the straw calibrate the scale.

(ii) It is of interest to repeat this experiment with the needle the same distance from the screw, but nearer, or further away from, the top surface of the straw. In which position is the straw balance most stable, and in which position is it most sensitive? Without further advice can you measure the mass of a grain of rice and the mass of its husk? Try measuring the mass of various insects, the mosquito, the mass of a drop of oil or a drop of water, a small length of wire (copper, iron, etc.) before and after heating, a hair from your head, and anything else you care to investigate.



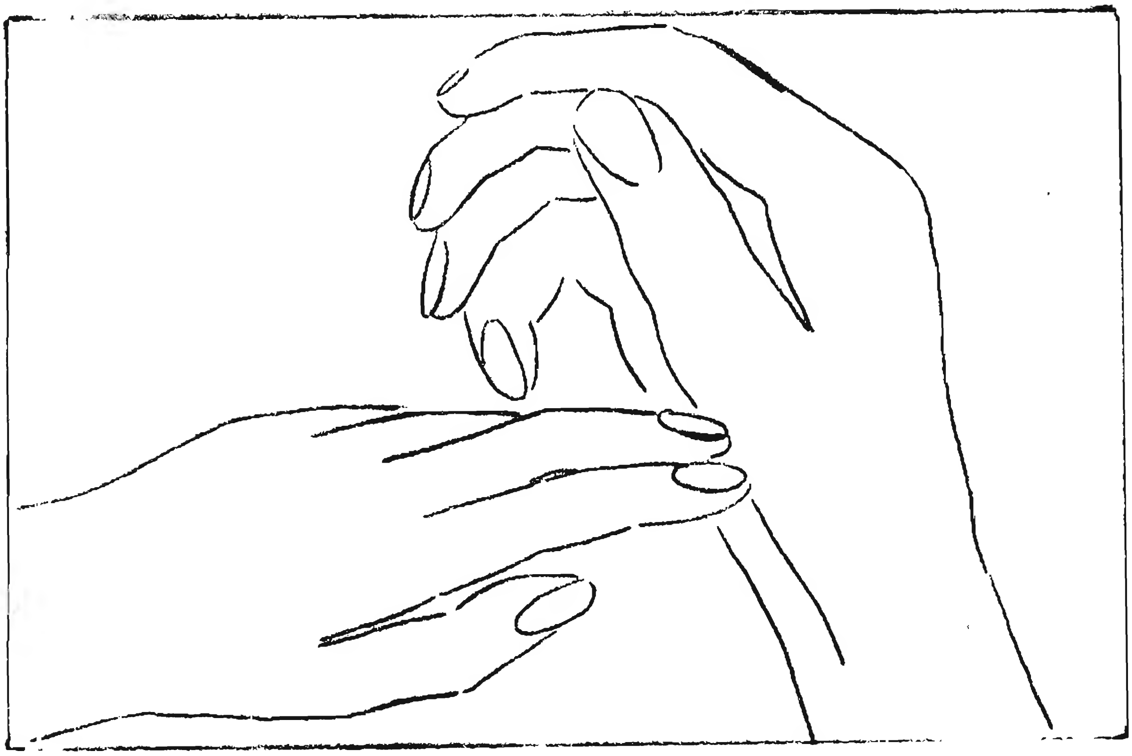
1.30 TIME

1.31 Simple Timing Devices

Apparatus Required:

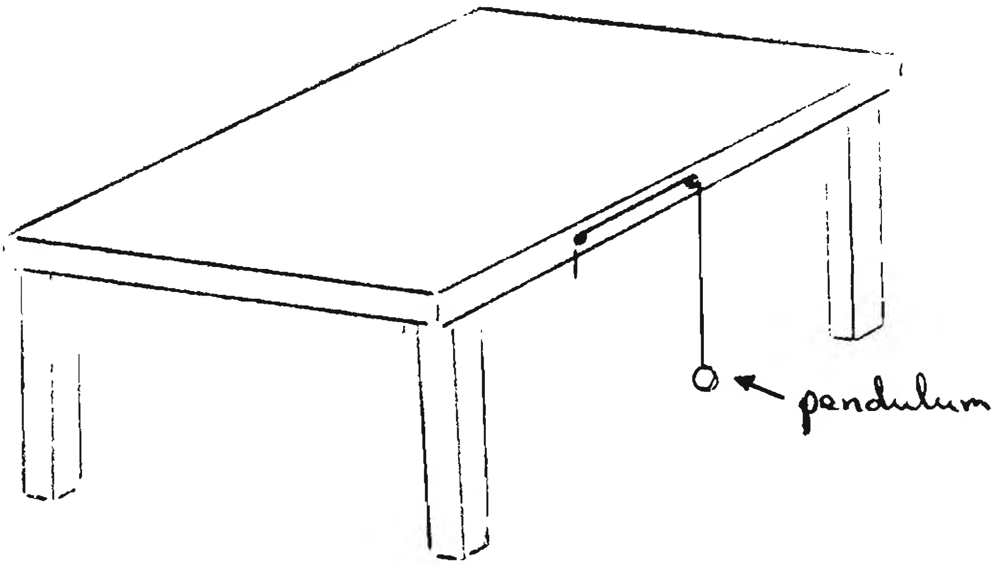
Qu.	Apparatus	Item No.
1 meter	String	
2	Brass balls, centrally drilled (diams. 1.2 and 2.4 cms)	
2	Thumb Tacks	
1	Meter Rule	

Activities



(i) Mark out a distance of say 5 or 10 meters and get your partner to practise walking at a constant speed between the points. When he feels that he can repeat the process at approximately the same speed use your pulse beat (placing two fingers of your left hand on the pulse in your right wrist) to determine how long (in terms of pulse beats) it takes for him to move from one point to the other. Repeat the process two or three times recording the rate of motion in meters per pulse beat.

(ii) Fasten one of the brass balls to the end of a length of string, suspending the newly created pendulum from the edge of the table



by means of thumb tacks. Then use the pendulum to measure the rate of walking of your partner once again, but this time in meters per oscillation (complete swing of the pendulum from, and back to, the same starting point).

Not only the pulse and the pendulum can be used to record the passage of time but many other devices. If you have a leaking water pipe and collect the drips in a can, the latter will fill at a fairly steady rate. The depth of water in the can will indicate the passage of time, and you will, in fact, have a simple time measuring device. If the rate of dripping varies the can will not fill at an exactly uniform rate, and the measuring device will be somewhat inaccurate. Many devices can be created to show the passage of time, but we must be very careful to detect irregularities in their behavior.

Let's refer back to our two original timing devices, the pulse and the pendulum, and compare them, seeking out any irregularities of behavior. Both you and your partner in turn should sit down and record the number of pulse beats corresponding to 20 oscillations of the pendulum. You will need the help of your partner in counting the oscillations as it is difficult to count the pulse beats and oscillations simultaneously. (All readings should be taken two or three times, and the average recorded).

(iii) Let's refer back to our two original timing devices, the pulse and the pendulum, and compare them, seeking out any irregularities of behavior. Both you and your partner in turn should sit down and record the number of pulse beats corresponding to 20 oscillations of the pendulum. You will need the help of your partner in counting the oscillations as it is difficult to count the pulse beats and oscillations simultaneously. (All readings should be taken two or three times, and the average recorded).

Now, get your partner to jump up and down vigorously about 30 times, while you remain sitting quietly. He should then sit down, and immediately compare his pulse beat with a further 20 oscillations of the pendulum. Can you explain your results?

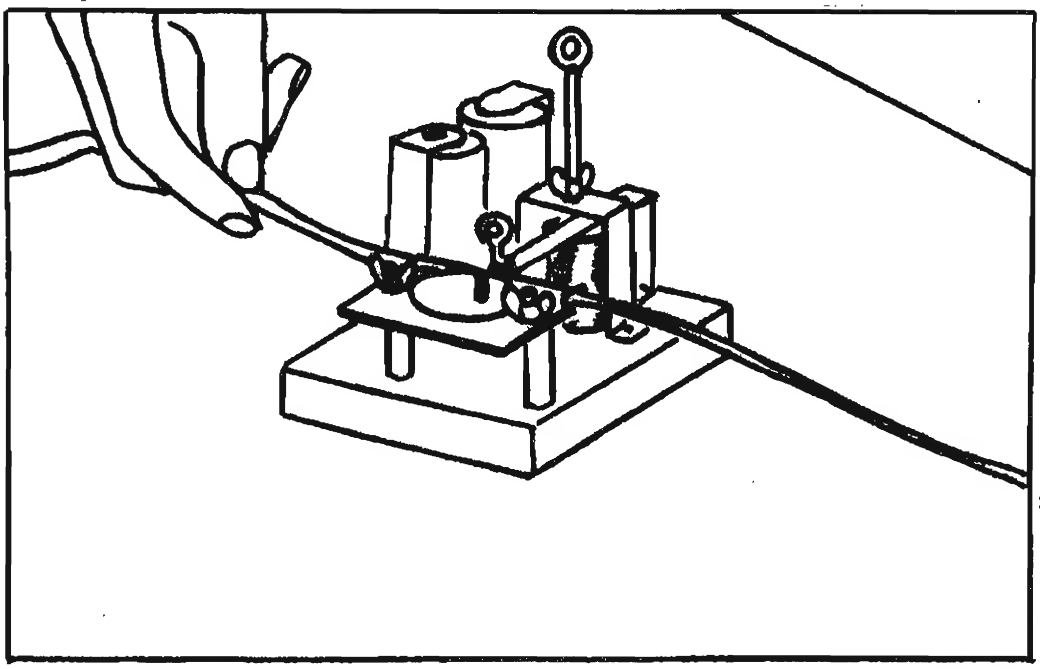
(iv) In using your pulse as a measuring device it is important that you should not jump about, and this should be kept in mind when taking further readings. It is now proposed that you should compare your pulse with 20 oscillations of the pendulum when the latter is 10, 25 and 50 cms long respectively. If you wish to use a pendulum to indicate a steady interval of time does it matter whether the length of the pendulum varies?

(v) Keeping the length of the pendulum fixed at 25 cms determine the number of pulse beats occurring in 20 oscillations of the pendulum first using a small pendulum bob (1.5 cm diam.) and then a large bob (2.5 cm diam.). Does changing the mass of the pendulum bob affect the rate of oscillation?

It is always useful to create standards, and a standard unit of time based on the pendulum could very easily be defined as the time required for one complete oscillation of a simple pendulum, 25 cms long. (The time required for one complete oscillation is referred to as the Period of the Pendulum). It is interesting to compare this interval of time against the standard interval of the second on the teacher's watch. Count the number of oscillations (of your 25 cm pendulum) which occur in a period of 20 seconds as indicated by your teacher's watch. The teacher will help by calling out the numbers zero to twenty at one second intervals. Does the result have any special significance?

1.32 Ticker Tape Timer

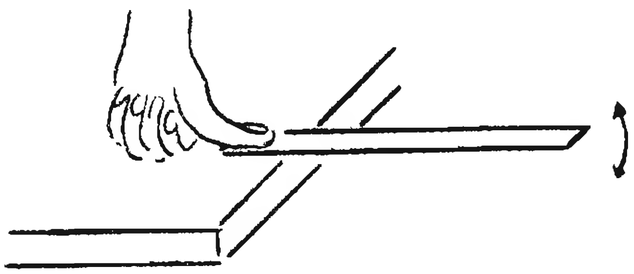
Apparatus Required



Qu.	Apparatus	Item No..
1	Ruler	
1	Ticker Tape Timer	1.30/01-02
1 roll	Ticker Tape	

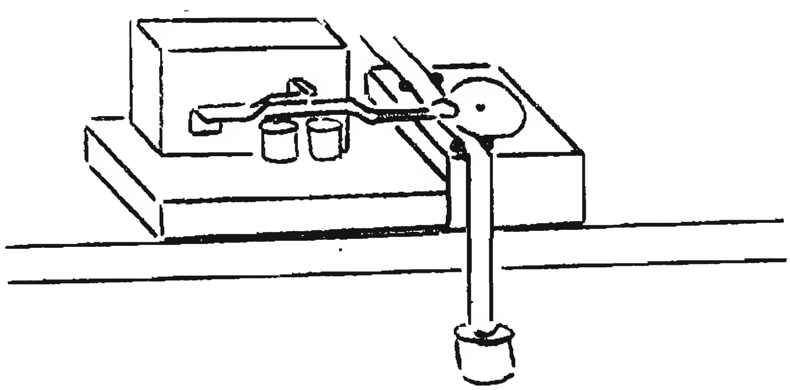
Activities

(i) Drop a metal object from the table to the floor. Can you calculate the time of fall in pulse beats or oscillations of the pendulum? If you reduce the length of the pendulum does it make the timing easier? The shorter the length of the pendulum the greater the number of oscillations that will occur while the mass drops to the floor.



Try holding one end of a hacksaw blade firmly on the table so that the free end can vibrate. By varying the length of the blade can you create a vibration which is so rapid that several oscillations occur while the object falls from the table to the floor? Can you count the number of oscillations when the vibration is so rapid?

The counting of rapid oscillations of a vibrating arm, such as the hacksaw, can be made very easy by means of the ticker tape timer. Each vibration is recorded on a moving tape, and if the tape is attached to a falling object the number of vibrations occuring while the object falls can be easily recorded.



To determine the period of vibration of your ticker tape timer pull a piece of ticker tape through the timer for a period of 5 seconds, and count the number of ticks that are recorded on the tape in that time.

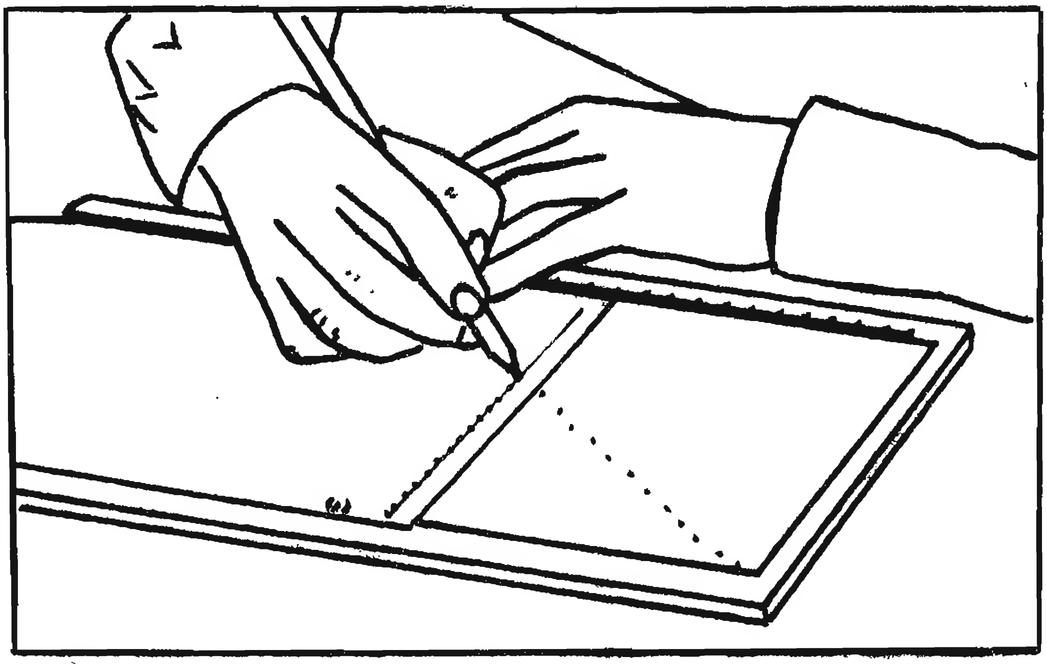
Hence calculate the number of vibrations of the timer per second.

Now use the timer to determine how long it takes a body to fall from the table surface to the floor. Attach the object to the end of the ticker tape, and then permit it to fall to the floor, pulling the tape through the timer. The distance the object falls can be marked off on the tape, and the number of vibrations occurring during the fall can be determined from the ticks on the tape. How long did it take for the object to fall to the floor?

1.40 FRAMES OF REFERENCE

1.41 Relative Motion

Apparatus Required



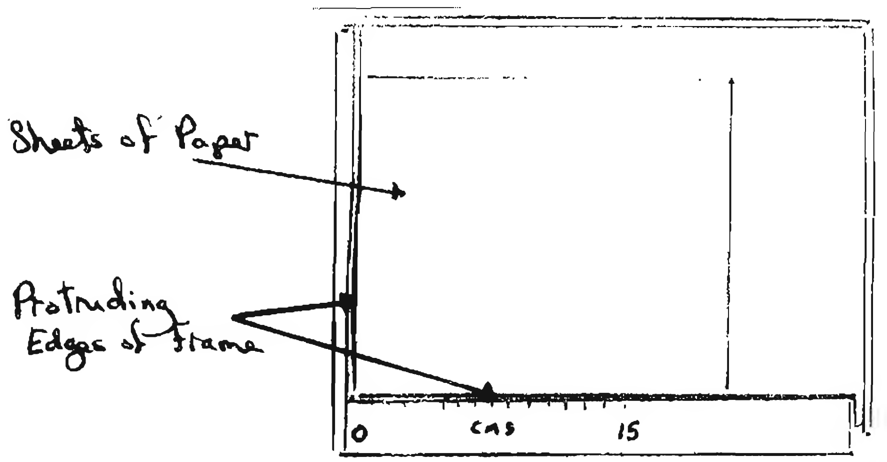
Qu.	Apparatus	Item No.
1	Relative Motion Frame	1.40/01
1 sheet	Carbon Paper	
2 sheets	Plain Paper	

Activities

(i) Take a pen and move it across a sheet of paper from point A to B. Indicate on the resultant line the direction of motion of the pen relative to the paper by means of an arrow marked P.

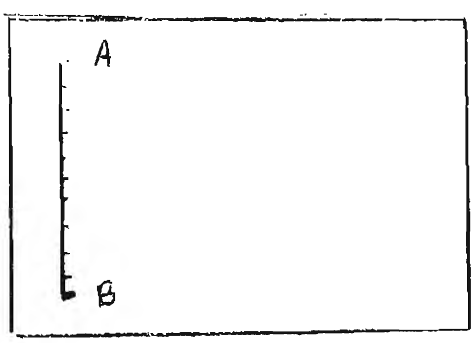
Then hold the pen stationary, but in contact with the sheet, and move the sheet in the opposite direction. A line AB will result once again. In this case use an arrow marked S to show the motion of the sheet relative to the pen, and a further arrow marked P to show the motion of the pen relative to the sheet.

(ii) Place a sheet of carbon paper between two plain sheets of paper, and place all three sheets on the relative motion frame with the edges of the sheets in contact with both protruding edges of the frame. Make sure that the carbon paper is placed between the plain sheets in such a way that any drawing on the upper sheet is also recorded on the lower one.



Let's now number the upper and lower sheets of paper 1 and 2 respectively.

Keeping all the sheets stationary draw a vertical line AB on sheet 1 marking off each centimeter moved. Then keeping your pen on the same fixed



point A on sheet 1, move the latter a centimeter at a time to the right, while sheet 2 remains stationary. This will produce a line on sheet 2, marked off in centimeters. Finally label all the lines on sheets 1 and 2 with the usual arrows indicating the motion of the pen relative to the paper, and vice versa.

You are now ready to try combining motions. Place the sheets back together exactly as they were before, or take clean sheets if you prefer. It is now proposed that the vertical motion of the pen along line AB should be combined with the left to right motion of sheet 1. This is best recorded by making a cross at point A on sheet 1. The pen is then moved one cm down the line AB, and the sheet is moved one cm to the right. The new position of the pen is recorded with a cross. This combination of motion is repeated with the pen until it has moved 10 cms down AB, and sheet 1 has moved 10 cms across sheet 2. Now study the resultant line on sheet 2 produced by the combination of the two motions. Can you indicate a simple rule for adding relative motions?

(iii) With the same apparatus, but clean sheets of paper for each combination try adding the following relative motions:

The motion of the pen from right to left across sheet 1 (moving 1 cm at a time) and the motion of sheet 1 from A to B (moving 1 cm at a time) across sheet 2. What is the resultant motion of the pen relative to sheet 2?

Increase the rate of motion of the pen only to 2 cms at a time, and see how the same two motions add together.

Finally move the pen vertically from A to B (1 cm at a time) across sheet 1 while sheet 1 moves across sheet 2, from left to right, at 2 cms at a time. What is the resultant motion of the pen to sheet 2?

Although you have been adding relative motions together in the form of distances moved, do you think you could add these together in terms of velocities?

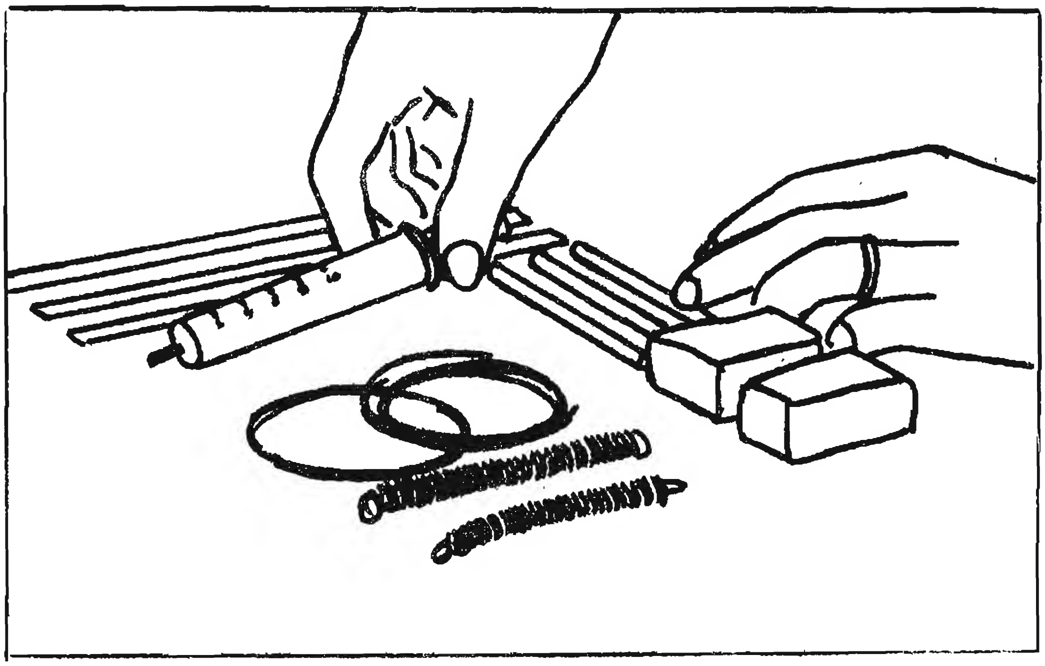
2. FORCES AND MOTION

2.10 INTRODUCTION TO FORCES

I wonder if you can describe a force, what it does and how you recognize it? Think of actual problems where you would say forces were exerted. For example, when a typhoon sweeps across the country the force of the wind knocks down houses and trees, the rivers fill as a result of continuous rainfall and the force of the swollen waters carry obstacles and bridges away. Even roofs, fences and cars are picked up and thrown before the wind. The force of impact of such obstacles can cause tremendous damage. These are just a few instances of forces being exerted by gases, liquids and solids. Can you think of a few more examples? Discuss such examples and see if you can formulate any ideas about what forces really are. You will then feel ready to try out these ideas in a series of simple experiments.

2.11 Effect of Forces on Solids, Liquids and Gases

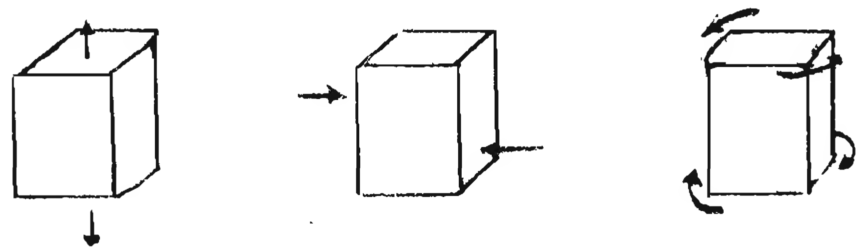
Apparatus Required



Qu.	Apparatus	Item No.
2	Cubes, approx. 5 x 3 x 2 cms (1 of Modeling Clay, 1 of Elastic Sponge Material)	
3	Metal Strips, approx. 20 x 1.5 x 0.05 cms (1 Alloy, 1 Lead, 1 Steel)	
1	Plastic Syringe	
1	Meter Rule	
1	Elastic Band	
2	Nails (10 x 0.7 cms approx.)	
1 meter	Copper Wire, #26 (Magnet Wire)	
1 meter	Steel Wire, #26 (Piano Wire)	
1	Wire Extender	2.10/01
1	Copper Spring	2.10/02
1	Steel Spring	2.10/02
1	Rebound Apparatus (with lead and steel balls)	2.10/03

Activities

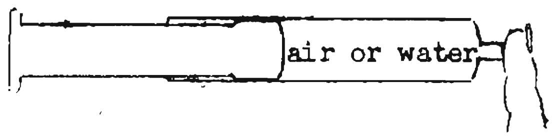
(i) When forces are exerted on a body the latter may move, or break, or simply be deformed. We are particularly interested in those instances in which a body is deformed. Take a cube of modeling clay and one of elastic sponge rubber. Try pushing, pulling and twisting the cubes. Do both cubes behave in the same way when subjected to forces? The pattern of behavior is in fact different with the different materials. In one



case you have a body being deformed by forces and showing no tendency to regain its shape. This is termed plastic behavior. In the other case the body is deformed by forces, but immediately regains its shape when the forces are removed. This is known as elastic behavior. Modelling clay (plasticene) and elastic sponge show almost perfect plastic and elastic behavior patterns, but most bodies fall short of these extremes indicating some intermediate pattern.

(ii) Take the lead, steel and alloy strips available, and try twisting and bending each in turn. See if you can recognize any tendencies towards plastic or elastic behavior in any of the strips.

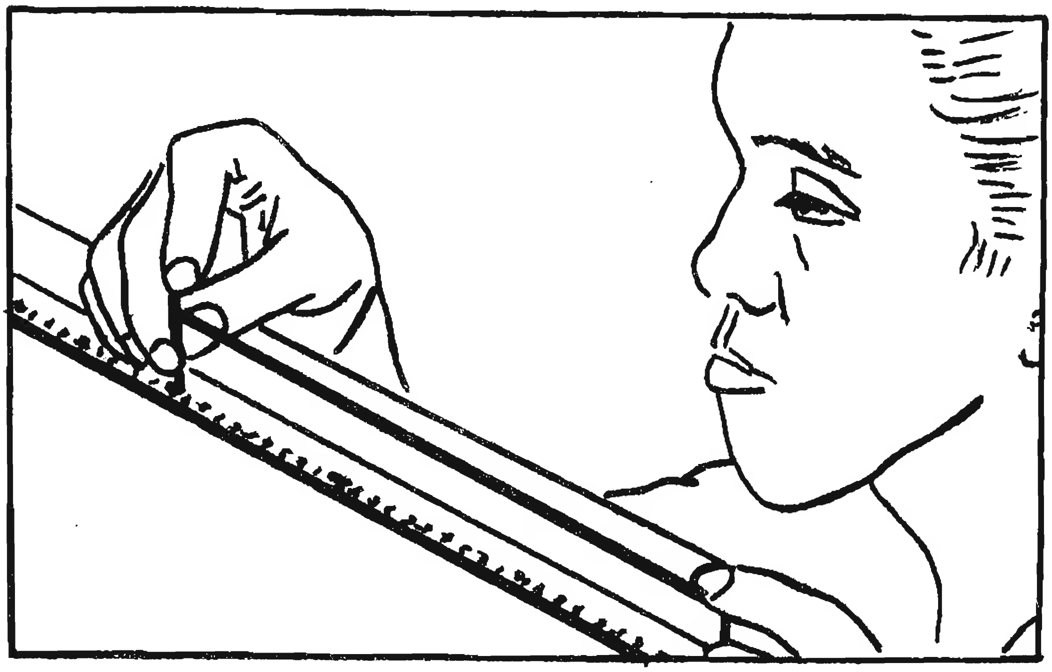
Take the plastic syringe, and try exerting forces on air or water contained within the syringe. How do these two substances behave?



Could any of the materials observed so far be used to indicate whether the forces exerted are large or small?

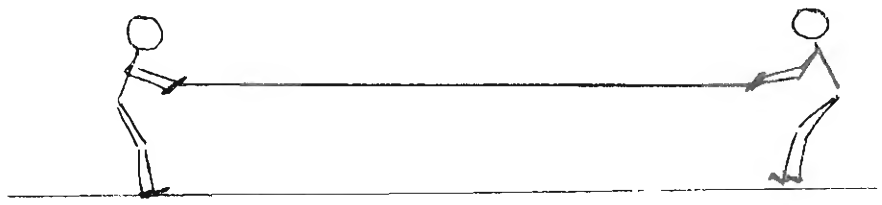
(iii) Take an elastic band, and get your partner to hold one end of the band stationary with his finger. Tell him to close his eyes while you vary the length of the band. Ask your partner whether the force exerted on his finger varies, and if so is there any relationship between the force exerted and the length of the elastic.

Now try extending the elastic band yourself until you feel that you are exerting the maximum force that the band can take without breaking. Take note of its length.



Extend the elastic about 10 times under the same maximum force, each time releasing the elastic. On the last occasion, note the length of the fully extended elastic band. Repeat the whole experiment with different quality elastic bands. Do you think that elastic bands can be used reliably to indicate the magnitude of forces by simply noting the extension of the band?

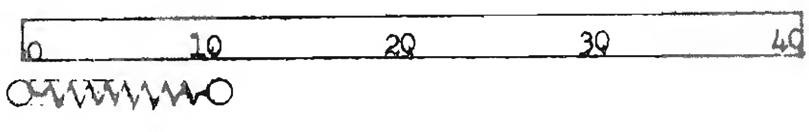
(iv) If you replace an elastic band by a copper or steel wire would you expect a similar form of behavior? A meter length of copper is provided for experimentation. Wrap each end of the wire securely around a nail, and use the latter as a handle in order to exert a large force on the wire. Get your partner to hold one end of the wire while you hold the other, and together pull gently on the wire. Increase the force by gradual steps.



If you can break the wire by pulling it at either end in conjunction with your partner, by all means go ahead, but always remember that once a material is destroyed that you have probably performed your last experiment on that particular item. In other words, make sure that you have made all possible observations before experimenting to the point of destruction.

A steel wire is not provided for student use for if steel wire breaks under tension it is likely to unleash itself causing cuts. In this instance it is preferable that the teacher demonstrates the behavior of steel wire under carefully controlled conditions using a wire extender.

(v) The comparable behavior of steel and copper wire might be more readily observed when the wire is in the form of a spring. 3 meter lengths of copper and steel wire have already been wound around a rod to form copper and steel wire springs.

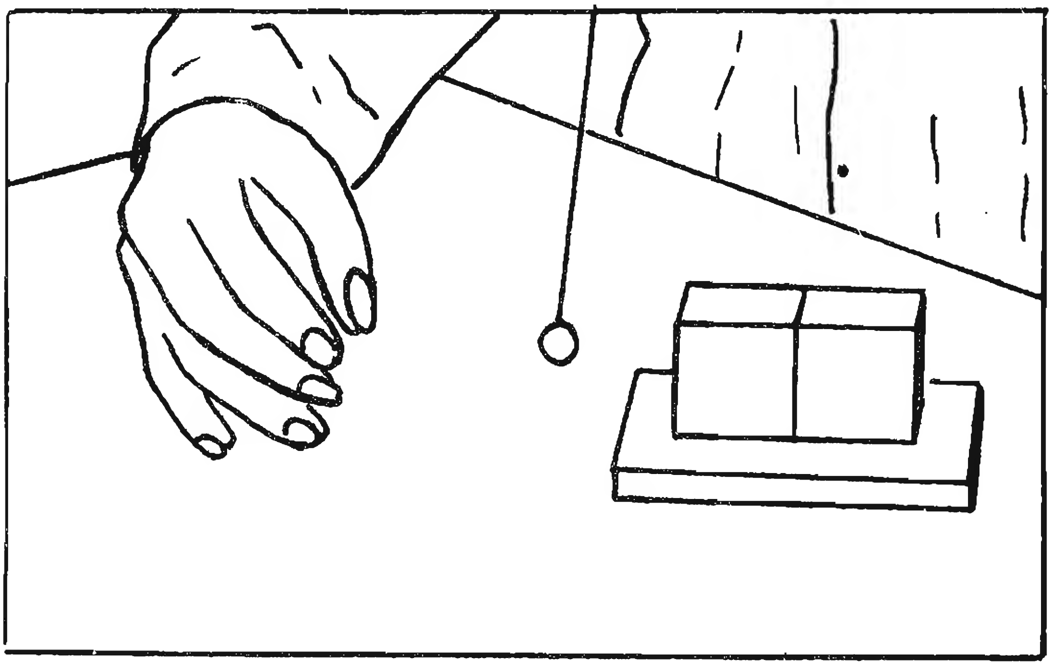


Take the copper spring and experiment on it with your partner trying to feel forces in much the same way as when experimenting with the elastic band. A cautious approach will provide you with the maximum information. Assuming the spring reaches the 10 cm mark on the ruler try extending it

to the 20 cm mark. Then release it and note its free length. Repeat the process extending the spring to the 20 and 30 cm marks noting the length when all forces are removed. Would you say that on all occasions when the spring is extended to the 20 cm mark the same forces are always exerted on it? Now repeat the whole experiment using the steel spring. Would you agree that as the spring is extended the force exerted on it increases, and that a given extension always indicates the same force, or would you qualify the statement? Which of the materials you have used so far could best be used to indicate the order of magnitude of forces? Do the materials have anything in common?

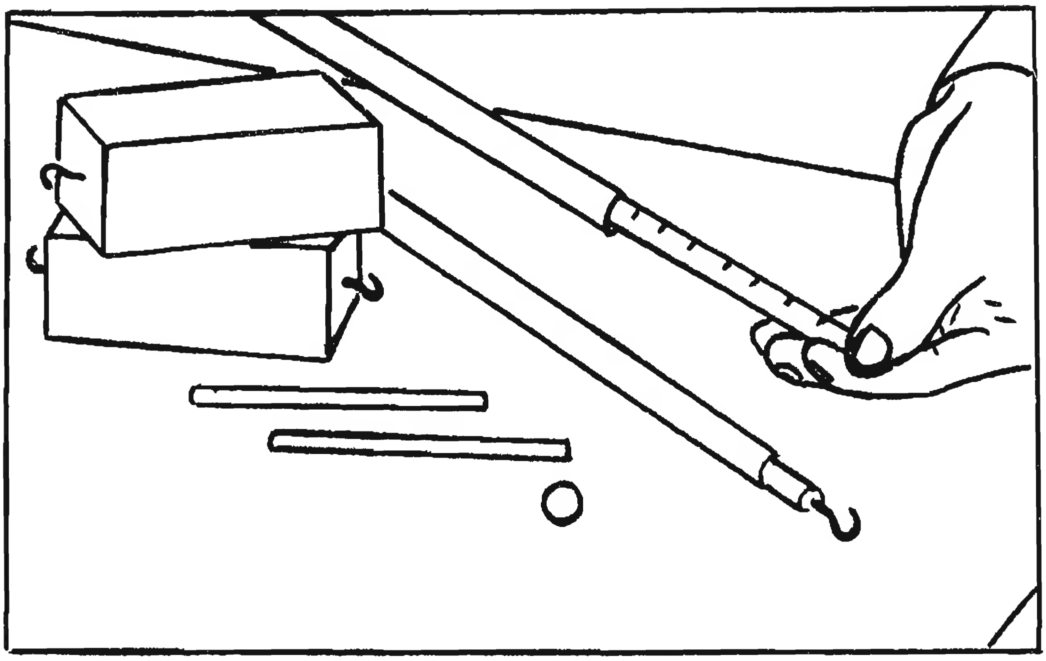
(vi) Finally let us try making an hypothesis (a prediction), and test this out in practice. You probably have already seen how elastic balls will bounce off floors and walls, and if you are not quite sure how a plastic (modeling clay) ball would behave, take a lump of modeling clay and drop it on the floor.

You might well guess that all elastic materials should bounce well, while plastic ones should hardly bounce at all. How would you expect a steel ball to bounce off steel, and how would you expect a lead ball to bounce off lead? First decide whether you expect lead or steel to behave elastically or plastically. Then having made your prediction test it out with the rebound apparatus provided.



2.12 Normality of State of Rest and Motion

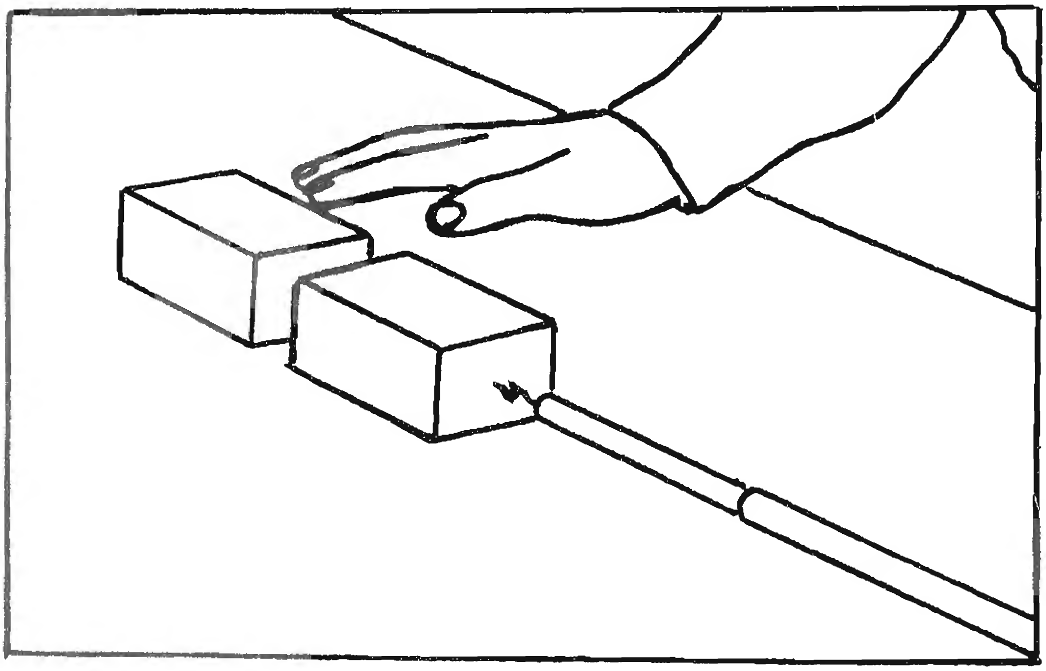
Apparatus Required



Qu	Apparatus	Item No.
2	Wooden Blocks (10 x 6 x 4 cms) (with cup screws either end)	
2	Spring Balances (measuring 1 Newton and 10 Newtons)	2.10/04
3	Steel Rollers (Nails 10 x 0.7 cms approx. with heads removed)	
1	Ball Bearing (0.8 cm diam.)	
1	Puck	2.10/05

Activities

(i) When a body is placed on a horizontal surface it tends to remain stationary. The reason is not so obvious, but the following activities might help you to discover the explanation. Take the two wooden blocks from the kit and place them horizontally, one on top of the other, on the table. Use a steel spring and a ruler to get some idea of the force required to keep the two blocks moving steadily across the table. You will have some difficulty recording the extension of the



spring and it is proposed that instead you use a spring balance, which is simply a device to make the extension of the spring more readily visible for recording. Repeat the experiment using first one block on top of the other, and then using only one block. Finally repeat the process when the block is placed on metal rollers. In these three instances is the force required the same in each instance? If not, could you explain the behavior by saying that motion is opposed by a force of friction? How, and where, could such a force be exerted?

(ii) Take the wooden block on its own, and give it a gentle push over the table surface. Now place the block on rollers and repeat the process. As the friction between the block and table gets less what happens to the resultant motion?

Try giving a ball bearing a gentle push across the table, and finally an air puck. In the latter case all contact between the object and the

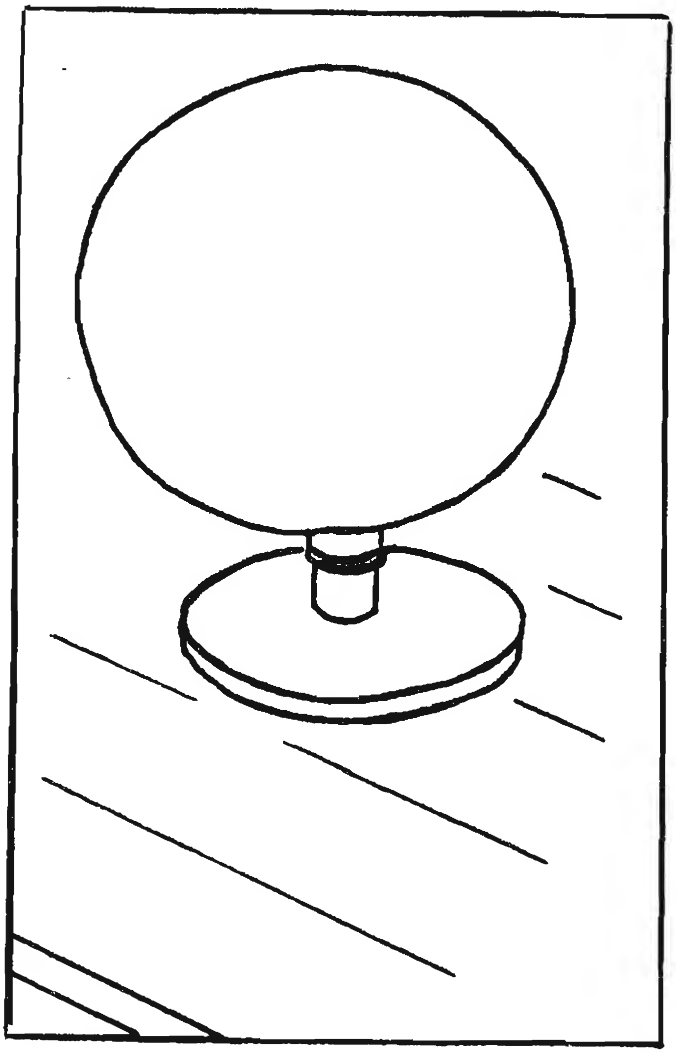
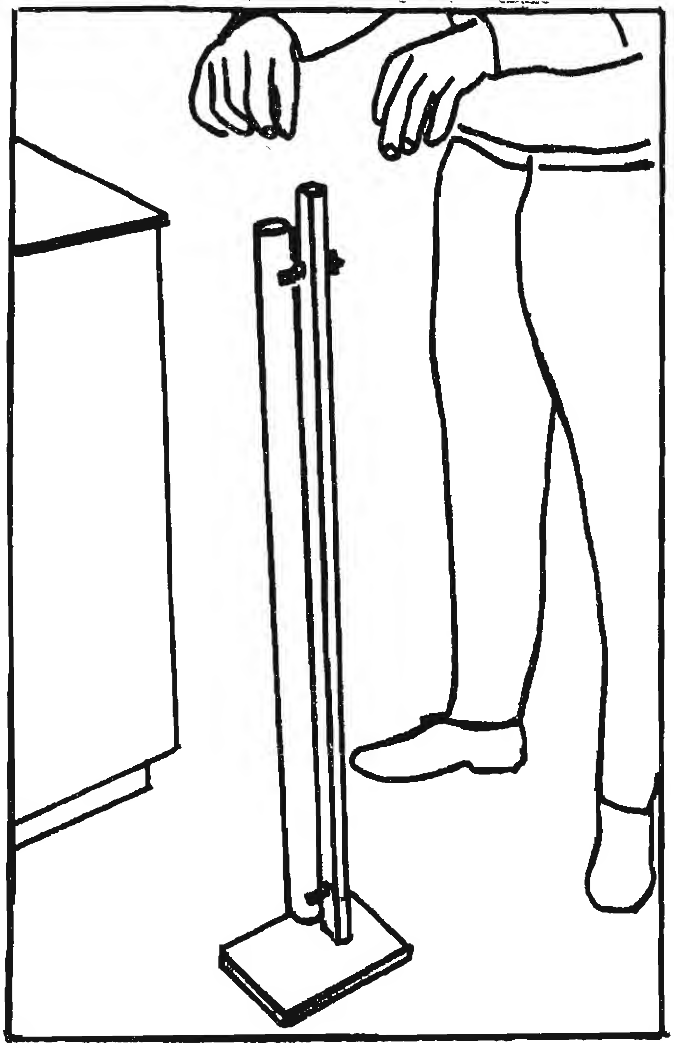


table top is removed, reducing friction to a minimum. Would you agree with the statement that a body will tend to carry on moving at a constant speed, or will tend to remain stationary, so long as no external forces (including friction) act on it? Can you think of any examples of continuous motion?

2.13 Contact Forces, Action Forces and Friction

Apparatus Required



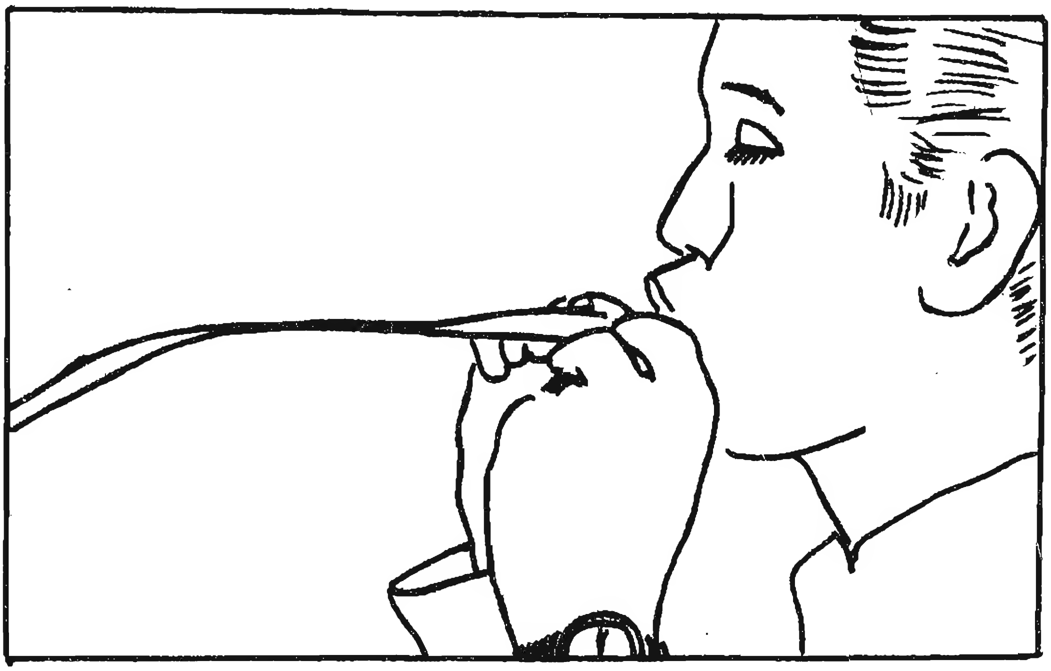
Qu	Apparatus	Item No.
1 sheet	Paper	
1	Friction Tube Apparatus	2.10/06
2	Ball Bearings (0.8 cm diam.)	

Activities

When we push or pull an object we exert a force on the object by direct contact between the object and the body. At the beginning of this section we referred to the various forces exerted by solids, liquids and gases during a typhoon. Would it be correct to describe these forces as contact forces?

(i) We have already seen the effect of friction exerted between solid surfaces, but are frictional forces exerted by the air on a moving body such as the puck? It is not difficult to investigate this. Take a sheet of paper (about 8 x 10 inches), and let it fall to the ground in such a way that the first time it remains parallel to the ground while falling, but the second time it remains roughly perpendicular to the ground. Fold the paper into a quarter, and later into a sixteenth, and repeat the experiment for each paper size. Do you conclude that frictional forces are exerted by the air on the paper? If so can you indicate how the surface area of the paper affects the frictional force exerted?

(ii) If you take a second piece of paper you can demonstrate for yourself the principle of airflow over an aeroplane wing. Hold one edge of the paper horizontal so that there is a slight tendency for the paper to be held in a horizontal plane. Place your lips close to the horizontal edge,



and blow horizontally under the paper. Then try blowing horizontally just above the edge of the paper. What happens? Are you surprised?

(iii) Finally the teacher will take a long glass container full of water, and drop two ball bearings simultaneously, one dropping through the water and one through the air. Do the ball bearings take the same time to drop through the same height? Would you say that liquids exert frictional forces, and if so are the forces exerted in liquids as great as those exerted in gases?

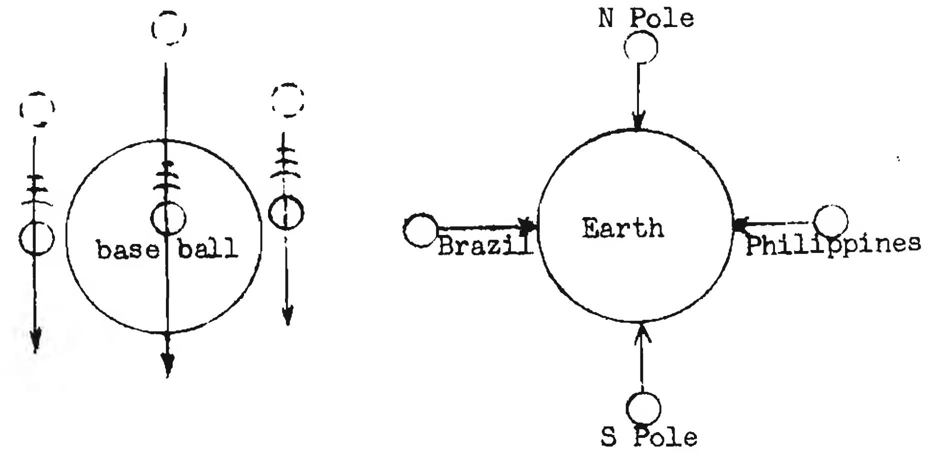
Whether we like it or not friction will always affect our experiments to some degree, and we should always be aware of it. If we suggest that frictional forces are negligible in a particular experiment we should convince ourselves first that this is true.

(iv) Do forces always have to be exerted by direct contact between bodies? Here are a few cases for investigation. Place the steel strip on the table alongside any other pieces of iron (such as nails) that you may have. Scatter these around a little and place one of the magnets on the table too. Take the second magnet, and bring it close to the various objects on the table, but try to avoid actual contact. What happens?

(v) Take the smallest possible fragments of paper that you can find, and scatter them around on the table top. Place one of the pieces of plastic from the kit on the table, and rub it with paper (not the fragments). Lift up the plastic, and bring it very close to the paper fragments. Does anything interesting happen? Have you seen the principle involved used in toys?

(vi) Take a stone in your hand, and let it drop on to, and near to, a spherical object such as a basket ball. Note the way in which the object falls past the ball. Then take a somewhat larger sphere (say the Earth) and try dropping objects close to it. Of course you would have some difficulty in traveling around the Earth in order to do this, but at least you can take one reading in your classroom, and then find out whether people have done similar experiments on the other side of the

world, and what sort of results would be obtained at the North and South Poles. Is there some evidence to indicate that bodies are



attracted towards the center of the Earth, immaterial of the location on the Earth?

2.14 Action and Reaction

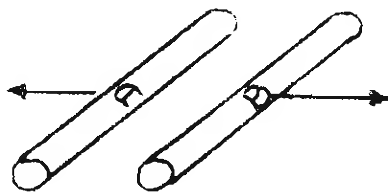
Apparatus Required

Qu	Apparatus	Item No.
1	Heavy Door Spring (Approx. 36 cm long, 1 cm diam.)	
2	Nails (10 x 0.7 cms approx.)	
2	Plastic Strips (10 x 2.5 cms)	
2	Cylindrical Steel Magnets (5 cm long, 0.8 cm diam.)	5.10/06

Activities

The three examples of action forces just introduced are usually referred to as magnetic, electrostatic and gravitational forces, and all are worthy of much more careful investigation.

(i) Take the two cylindrical magnets, and lay them together on the table in such a way that they repel one another. Hold the magnets in contact, and then release them simultaneously. Note the resultant action (with small chalk marks on the table or some other simple device). If you label the magnets A and B, can you determine whether magnet A pushed B, or vice versa?



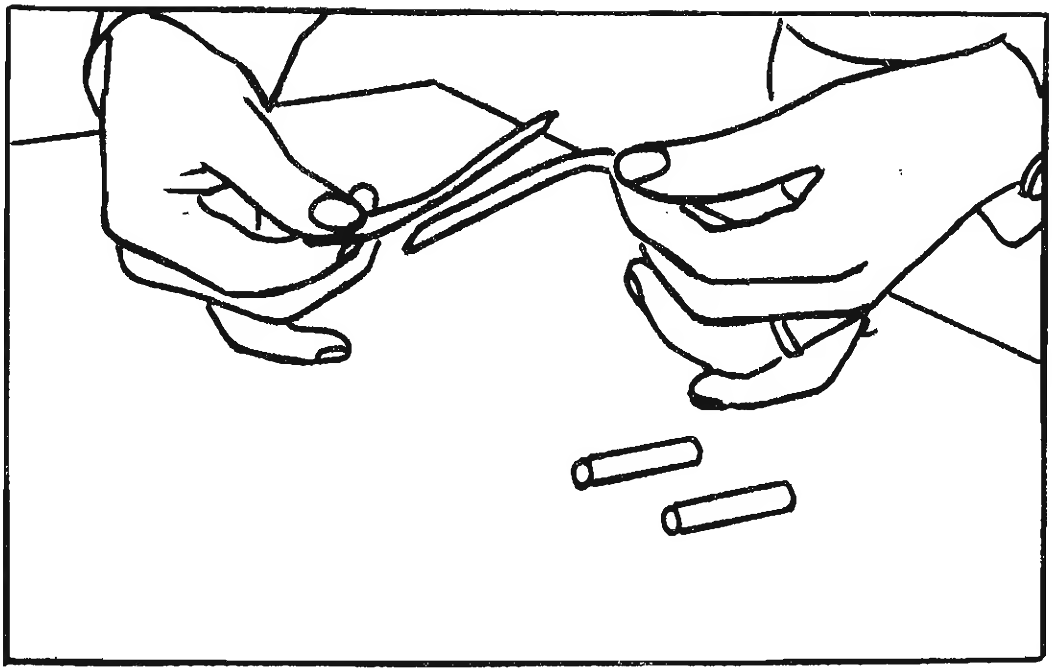
If you hold the magnets together again, and release only B, how far does it travel from A compared with the total separation when A and B were released simultaneously? Repeat the experiment releasing A while B is held stationary. Is it possible for magnet A to push B without B pushing A, and if not are the forces exerted by A and B comparable in size?

An interesting variation of the above experiment is to reverse one of the magnets so that they tend to roll together, when placed parallel to one another. Try moving both magnets a little at a time towards one another. Note their positions when they are magnetically attracted to one another. Then hold A and find out how close B can be brought before magnetic attraction becomes obvious. Repeat the experiment holding B stationary and bringing up A.

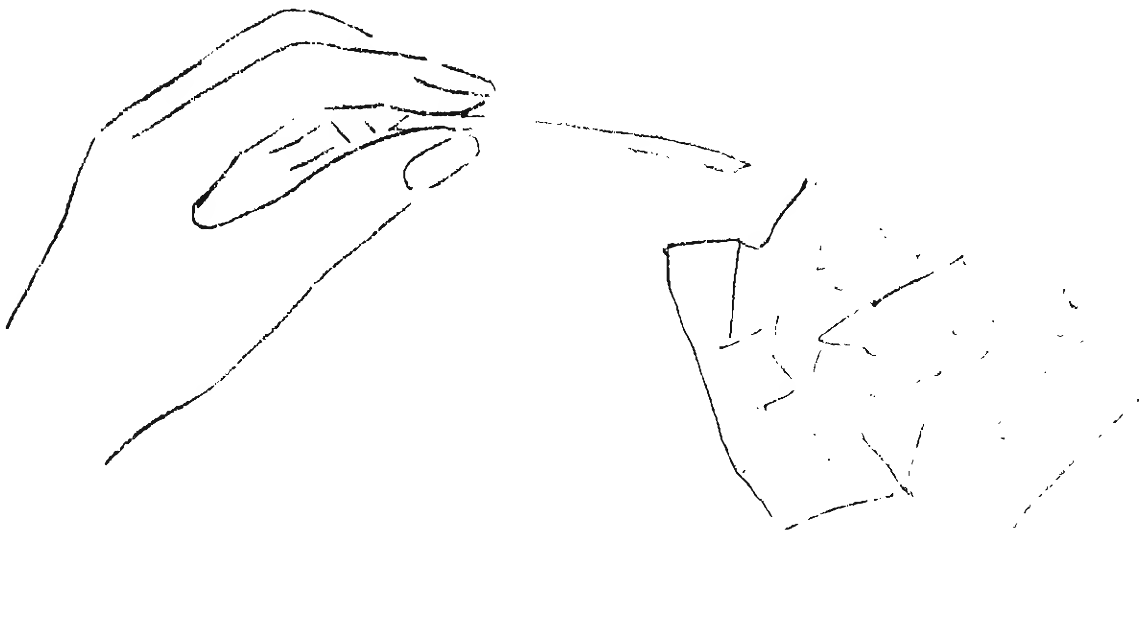
The major question to be answered from this investigation is whether it is possible for a force to act on a body without this same body reacting on the original body. Further, if we conclude that wherever there is an action force there must be a reaction, can you make a rough guess at the comparable magnitudes of these forces of action and reaction?

(ii) This problem is well worth investigating when other types of forces, such as electrostatic forces, are involved. Place the two plastic strips, on the table and rub each separately with paper. Then take the strips and hold

them close to one another in the air. Is there any evidence of action and reaction?

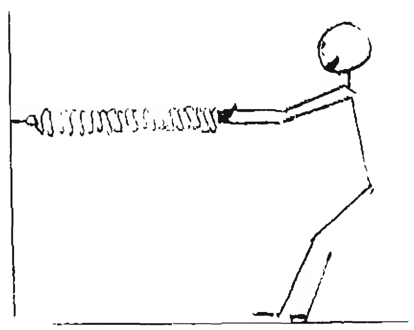


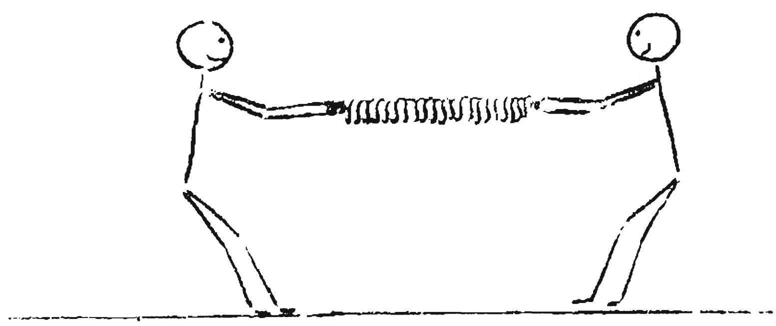
It is also of interest to bring the used paper close to the newly rubbed plastic strip. What happens?



Scientists tell us that in just the same way that magnetized bodies and electrostatically charged bodies will attract one another so masses will attract one another. In fact, they claim to have effectively demonstrated this attraction in the laboratory. They tell us that the larger the masses the greater the force of attraction, but the further the distance between their centers the smaller the force will be. If this is true why is it that two steel balls placed close together on a horizontal table do not roll together, and why is it that if you increase the masses involved and consider two cars standing close together on a level road that the cars do not roll together under the force of attraction? If you returned to the example of the steel balls can you think of any way of replacing one of the balls by a sphere many millions of times greater? If you can do this the force exerted between the two spheres should be millions of times greater, and maybe you could observe the effect of this force.

(iii) So far in discussing action and reaction only action forces have been involved. The teacher will now conduct a demonstration using two students who appear to be equally well built, and equally strong, to investigate action and reaction when contact forces are involved. The first student will pull on a strong door spring hooked to the wall, and see roughly what force he can exert on it in a horizontal direction by taking note of the extension of the spring. The second student will repeat the process.





The spring will then be removed from the wall, the students will exert maximum horizontal forces on either end of the spring, and the class will note the new extension of the spring. Does the new extension indicate the same force extending the spring or twice the force exerted by one student. Can

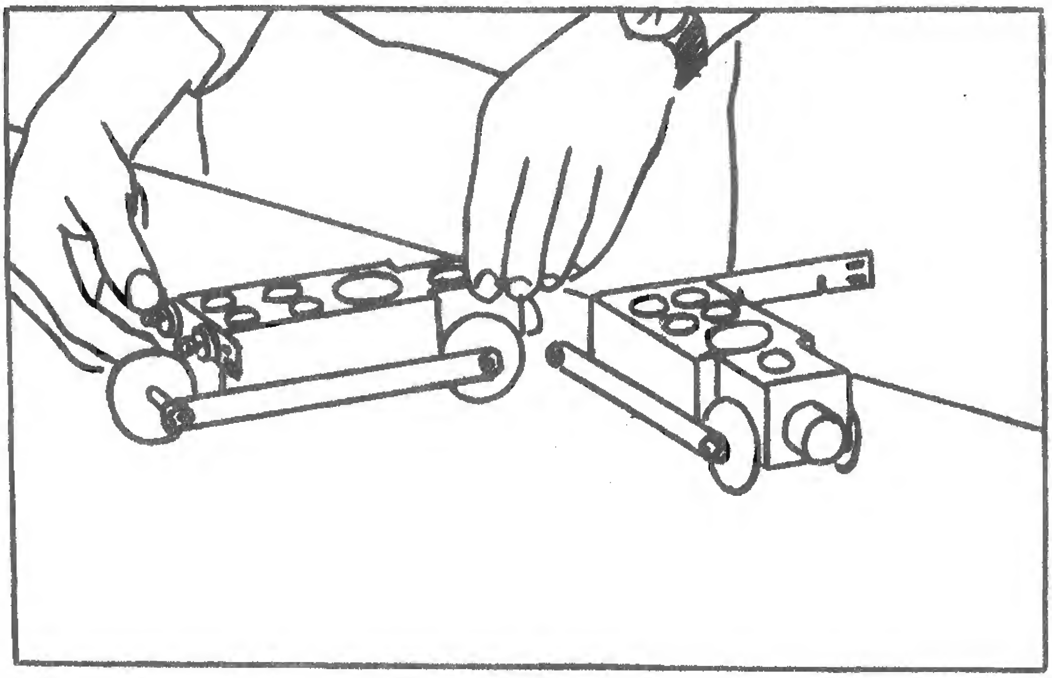
you explain this? Is it possible for the wall hook in the original experiment to exert a force in reaction to the action of the student?

Finally, when students of equal build exert forces simultaneously on both ends of the spring, the latter extends but does not move. However, what happens if a big boy is placed at one end of the spring and a much smaller one at the other end? Try it and see. Can you relate the forces exerted on the body with resultant motion in any way? Does a force always cause motion? If not what does cause motion?

2.20 MOTION

2.21 Analysing Motion

Apparatus Required

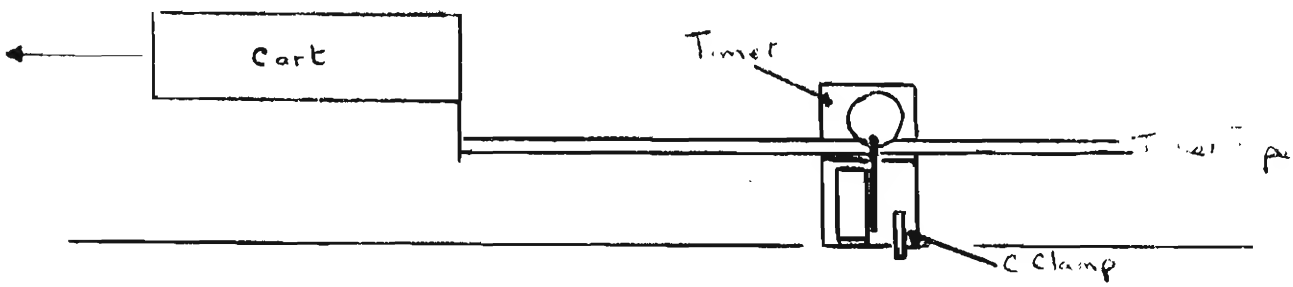


Qu	Apparatus	Item No.
1	Cart	2.20/01-02
1	Inclined Plane	2.20/03
1	C Clamp	2.20/04
1	Ticker Tape Timer	1.30/01-02
1	Meter Rule	
1	Chain of Elastic Bands (approx. 40 cms long)	
1	Thumb Tack	

Activities

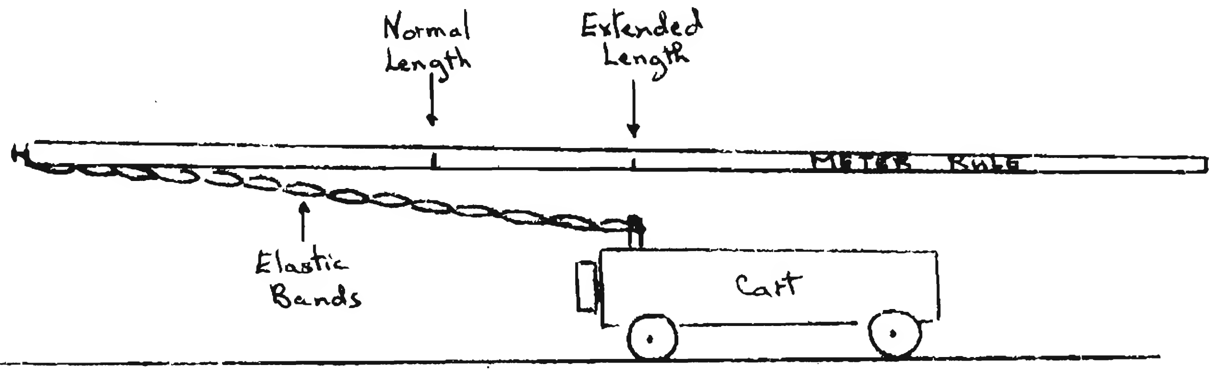
(i) A study of motion is simplified by the use of a ticker tape timer. To understand fully how this works try pulling ticker tape through it at varying speeds, slow, quick, stop, quick, stop, slow. Mark clearly on the tape which regions correspond to each of the above motions.

(ii) Clamp the timer to the table. Pass the ticker tape through the timer, and attach the tape to the cart so that the motion of the cart across the table surface (or horizontal surface of the inclined plane) may be recorded on the ticker tape. Give the cart a push across the table, and observe the



resultant motion recorded by the ticker tape.

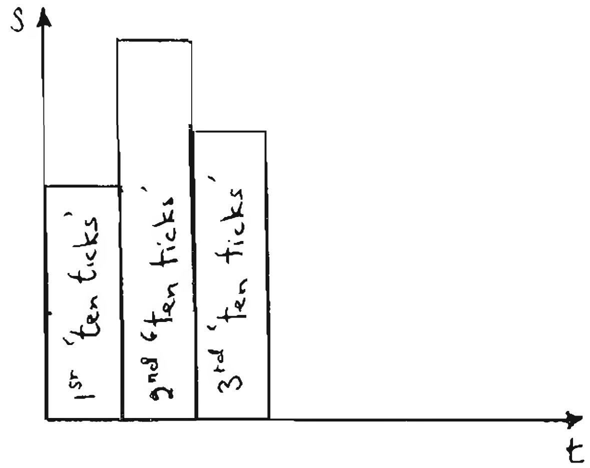
It is instructive to repeat the experiment giving the cart a somewhat more controlled push by means of stretched elastic bands. Take a number of elastic bands (say 10), and attach these together to form a single chain. Fasten one end of the chain to the end of a meter rule and the other end to the spring release on the cart. Note the normal length of the chain. Then holding the meter



rule firmly in position move the cart backwards thus extending the elastic chain. Note the extension. Set the ticker tape in motion, and remove your hand from the cart thus permitting the stretched elastic chain to propel the cart forward.

Study the resultant motion by means of the ticker tape. In particular note the initial extension of the elastic band, and compare the same distance of initial motion as recorded on the ticker tape. What do you notice about this first short distance of motion compared with the remainder?

To study the motion more carefully, mark off consecutive 'ten tick' intervals along the tape. Each 'ten tick' represents a fixed interval of time (1/5th sec if the rate of vibration is 50 per sec). Cut the tape into 'ten tick' intervals, and create a graph showing the distance 's' traveled in each interval 't' of time. The average velocity during each interval of



time may be obtained by measuring the distance 's' traveled in the interval. The velocity should be expressed in cms per 'ten tick', although it is not difficult to convert to cms per sec. During which interval does the cart have maximum velocity? Does the motion slow down regularly, and if so why?

(iii) Attach the timer to the inclined plane with a C clamp, and pass the ticker tape through the timer to the cart in the usual way. Release the cart from the top of the slope, giving it a small initial push with the help of the meter rule and elastic chain. Study the resultant motion with the help of the ticker tape, once again marking off 'ten tick' intervals and creating a graph. Repeat the experiment with different inclinations of the plane. Can you produce an inclination which will result in constant velocity of the cart? Such a slope would be such as to compensate the motion of the cart for the effect of friction.

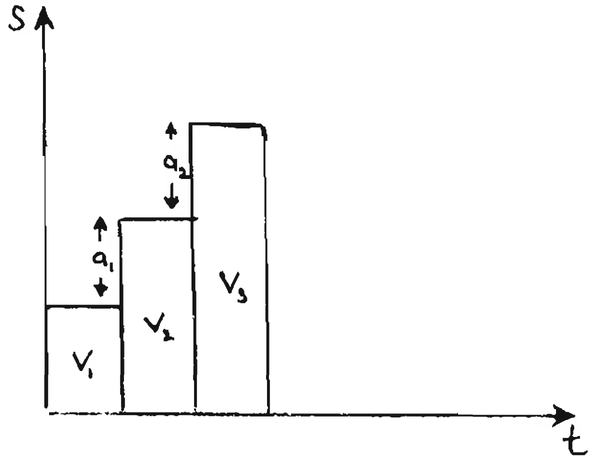
2.22 Acceleration

Apparatus Required

Qu	Apparatus	Item No.
1	Cart	2.20/01-02
1	Inclined Plane	2.20/03
1	C Clamp	2.20/04
1	Ticker Tape Timer	1.30/01-02
1	Meter Rule	
1 meter	String	
1	Pendulum Mass (Any mass such as a lump of lead)	
1	Mass, approx. 500 gms (piece of brick)	
1 sheet	Paper	

Activities

(i) Increase the slope of the plane, to say 20 degrees, so that the cart will run freely all the way down without any initial push. Use the ticker tape to analyze the motion in the same way as before, producing a graph of distance 's' traveled in each 'ten tick' interval 't'. Record on the graph



the average velocity during each interval of time. By how much does the velocity increase with each successive time interval? This quantity is called the acceleration 'a' and should be recorded on the graph. If each velocity is recorded in cms per 'ten tick' interval, then the increase (or acceleration) would be indicated as an increase in velocity of so many cms per 'ten tick', for every interval ('ten tick') of time. In the same way if the velocities were measured in miles per hour at one second intervals, the acceleration would be recorded as being so many miles per hour per second. Having recorded the acceleration (cms/'ten tick'/'ten tick') for each interval of time, study the values carefully. Do you notice anything unusual about the values?

Work out the average velocity over the first three intervals of time.

$$\bar{V} = \frac{V_1 + V_2 + V_3}{3}$$

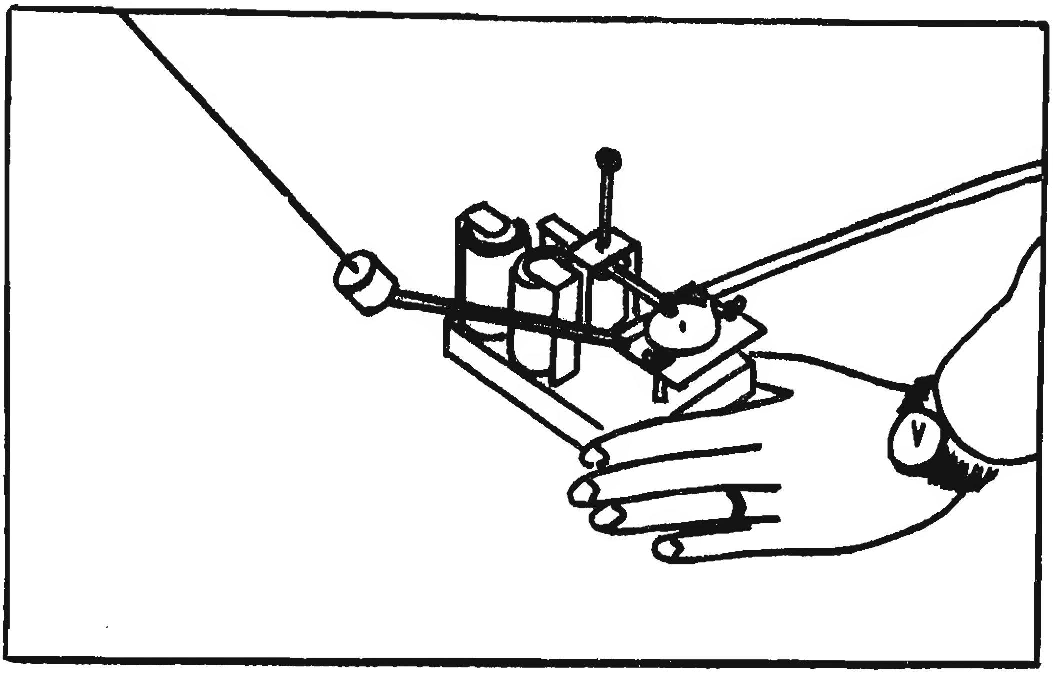
Can you also obtain the average velocity over the same three intervals by averaging the initial and final velocity for the period?

$$\bar{V}' = \frac{V_1 + V_3}{2}$$

How do the results compare with one another, and how do they compare with the velocity during any one of the three intervals? Don't jump to conclusions

too rapidly. Try averaging the velocities over 5, 7, 9 intervals of time using the same techniques. It might help you to draw up clear observations if you make some form of table to compare your results.

(ii) It is interesting to observe the motion of a pendulum in a similar way. A simple pendulum can easily be made from a meter length of thin string and a bob of lead (about 2 cms in diameter) or some such mass, attaching the

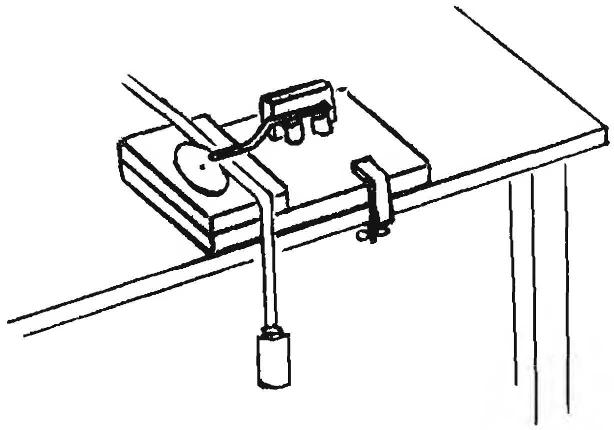


free end of the string to the side of the table with a thumb tack. Attach ticker tape to the bottom of the pendulum bob and pull the pendulum sideways about one meter. One complete swing of the bob may be recorded on the tape. In this case it is suggested that a 'five tick' interval of time will be more suitable for analysis of the movement because of its rapid motion.

Create a graph showing the distance traveled in each 'five tick' interval, and record the average velocity during each interval on the graph. In the same way as before measure the acceleration between each interval, recording velocities in cms per 'five tick', and the acceleration as cms per 'five tick' per 'five tick'. Record all the values of acceleration on the graph.

Just as in the previous experiment try averaging velocities over 3, 5, 7 and 9 intervals of time. What do you notice about the averages determined by different methods? From the two acceleration experiments can you draw any general conclusions?

(iii) With your new found knowledge can you analyze the motion that results from the pull of the Earth on a body? Take a mass (a lump of lead, etc.) of about 500 gms, and let it fall through about 1 meter. Trace the



motion with a ticker tape. Using a suitable time interval (in this case a 'three tick' interval) determine whether the resultant motion shows constant or variable velocity, constant or variable acceleration. How do your results compare? Would you expect the motion to be affected by friction?

(iv) The previous experiment gives some indication that bodies of different masses fall to the Earth with similar acceleration. Let's study this a little further by taking two bodies of very different mass such as a heavy stone and a sheet of paper. Drop the two simultaneously from the same height so that the plane of the paper is parallel to the floor. What do you observe?

Now fold the paper in half several times over until it occupies the smallest possible space. Once again release the paper and stone simultaneously from the same height. What happens?

Folding the paper for the second activity in no way alters its mass, but it does reduce the retarding effect of air friction. Assuming the friction on all falling bodies on the Earth is negligible would you expect any similarities between the rates at which different masses fall?

2.30 FORCE AND MOTION

2.31 Force, Mass and Acceleration

Apparatus Required

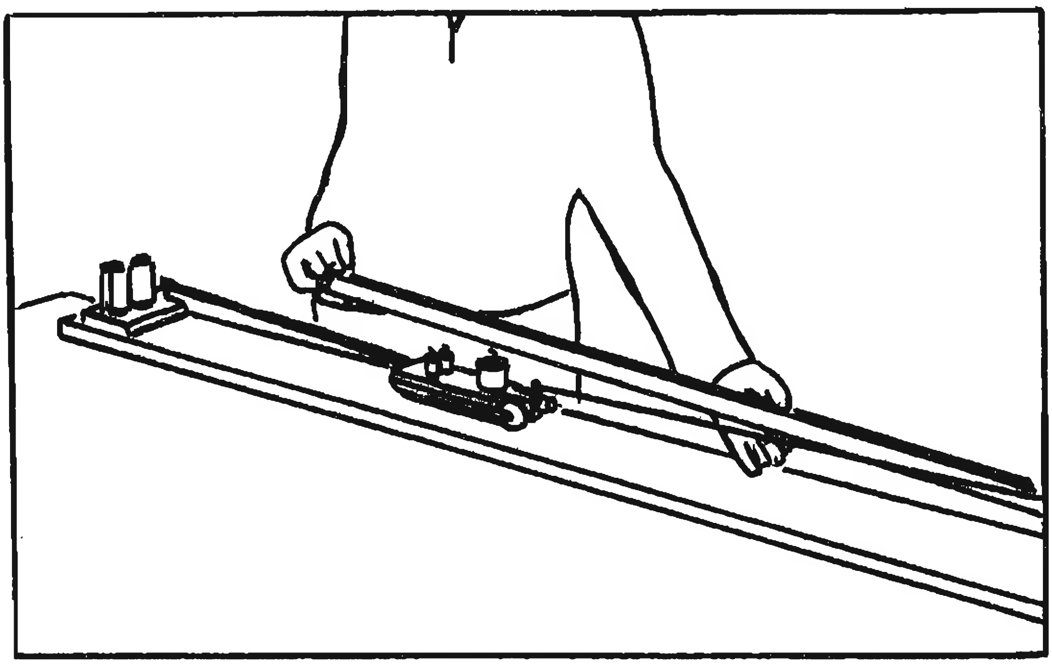
Qu	Apparatus	Item No.
2	Cans (Identical external appearance, but one loaded with soil and one empty)	
1	Cart	2/20/01-02
1	Box of Weights	1.20/02
1	Ticker Tape Timer	1.30/01-02
1	C Clamp	2/20/04
1	Inclined Plane	2/20/03
1	Spring Balance (1 Newton)	2.10/04
2	Chains of Rubber Bands (Approx. 40 cms long)	
1	Thumb Tack	

Activities

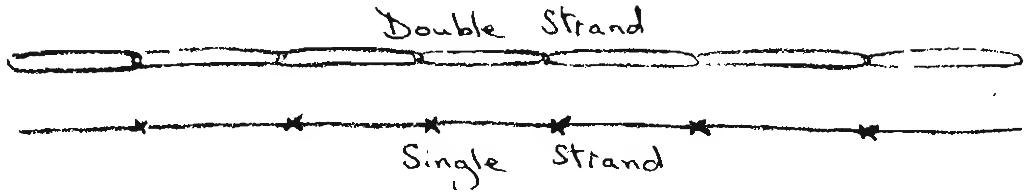
(i) The teacher will take what appear to be two identical cylinders, and lay them on the horizontal surface of a table. You will be invited to push either cylinder very gently with the back of your smallest finger, but you will not be permitted to lift up the cylinders. Now call upon your knowledge of everyday experiences, and try to account for the different behaviors observed in this simple experiment. Resist the temptation to pick up the cylinders before you have reasoned out why they behave differently.

If you are still not too sure take a cart and try pushing it along a horizontal surface, first loaded and then unloaded. You should now have some positive suggestions. What happens if you vary the magnitude of the push? Does the mass of the body affect its motion in any way? What type of motion results in each case? It is doubtful if you can answer all these queries from such simple observations, but at least you may have formulated some ideas or theories which are worth investigating more thoroughly.

(ii) It is proposed that you should study the effect of force on motion much more carefully now. The cart provided has a mass of 400 gms, and it is very convenient in this experiment to increase this to 1,000 gms by adding further masses. An inclined plane should be used to compensate for friction, and it should be noted that the frictional effect varies according to whether the tape is attached to the cart, and depends on whether the vibrator is operating. The ticker tape should be used to determine when the motion is fully compensated for friction. A small wooden strip placed under the end of the plane makes it possible to adjust the slope of the plane quite accurately.



Take a chain of rubber bands for the first experiment, and cut the bands in such a way so as to form a single strand of elastic, rather than a double strand as in the original chain.



Attach one end of the chain to the end of a meter rule with a thumb tack, and the other end to the release spring on the cart. Holding the rule steady move the cart backwards to extend the chain by a fixed amount (say 10 cms). On releasing the cart move the ruler in the direction of motion of the cart, at the same speed as the cart, thus maintaining the same fixed extension in the elastic chain, and hence applying a constant force to the cart during the motion. Repeat this activity until you feel that you can maintain the fixed extension of the strand throughout the motion with only a slight variation. Now repeat the activity with the timer operating, and analyze the resultant motion.

The same experiment may now be performed with twice the force acting, by using one of the original chains of rubber bands (double strand, not single) extended by the same fixed amount as before. On the same basis it is proposed that you analyze the motions resulting from the application of forces of magnitude F_o, $2F_o$, $3F_o$, and $4F_o$ (where F_o is the force exerted by one strand alone extended by a fixed amount). It is always a good idea to check your results by performing each experiment more than once.

What type of motion results under each of the forces? Is there any form of relationship between the motions?

(iii) Empty the cart, and once again check the slope of the inclined plane for friction compensation. Is the slope the same as when the cart was loaded? It is now proposed that the cart should be run along the plane several times under the same force F_o that is exerted by a single elastic strand, but the mass of the cart should be varied for each run. Thus if m_o represents the 400 gm mass of the cart, add masses so that the total mass

of the cart in successive runs will be m_o, $2m_o$, $3m_o$, and $4m_o$. In each case analyze the resultant motion using ticker tape. At the end of the experiment check whether the slope is still well compensated for friction when the total mass of the cart is $4m_o$. Does this give you any ideas as to how the experiment might be improved? Do your results indicate any particular relationship between mass and motion? You might like to investigate this more carefully by increasing the mass of the cart for each motion by a hundred gms at a time until the total mass is 800 gms, and thereafter by 200 gms at a time until the total mass is 1,600 gms. It will be helpful if you tabulate your results carefully. Can you record your results on a graph? You should discuss this with the teacher.

(iv) A group of students performed the above experiments for us and came up with some interesting observations. If your results are similar to those obtained by our students they will indicate that when the mass of the cart remains constant the forces applied produced a uniform acceleration which increased with increasing force. The result might be summarized in the form:

$$a \propto F \text{ (if m is constant)}$$

The second set of experiments showed that the single elastic strand always produced uniform acceleration, but that this decreased as the mass of the cart increased. The result might be summarized in the form:

$$a \propto \frac{1}{m} \text{ (if F is constant)}$$

It would seem that the two results might be combined together to form the following relationship:

$$a \propto \frac{F}{m}$$

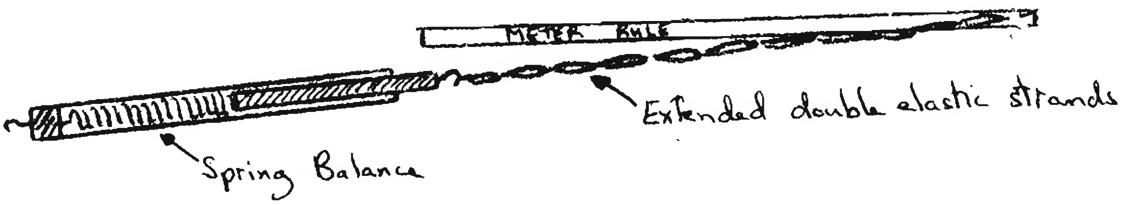
$$\text{or } F = k.m.a \text{ (where k is a constant)}$$

We can make the unknown constant equal to 1 by defining the force that makes a 1 kgrm mass accelerate at 1 meter/sec/sec as being a unit force which we call 1 Newton. Thus so long as the mass of a body is indicated in kgrms, and its acceleration in meters/sec/sec the equation

$$F = m.a$$

will indicate the force causing the body to accelerate, so long as the force is indicated in Newtons.

(v) Now check the results of your first experiment using the cart with its mass fixed at 1 kgrm. Note the acceleration produced in the cart using 1, 2, 3 and 4 elastic strands when each is extended by the same fixed length, and thus calculate the force (in Newtons) exerted by 1, 2, 3 and 4 strands respectively placed parallel to one another.



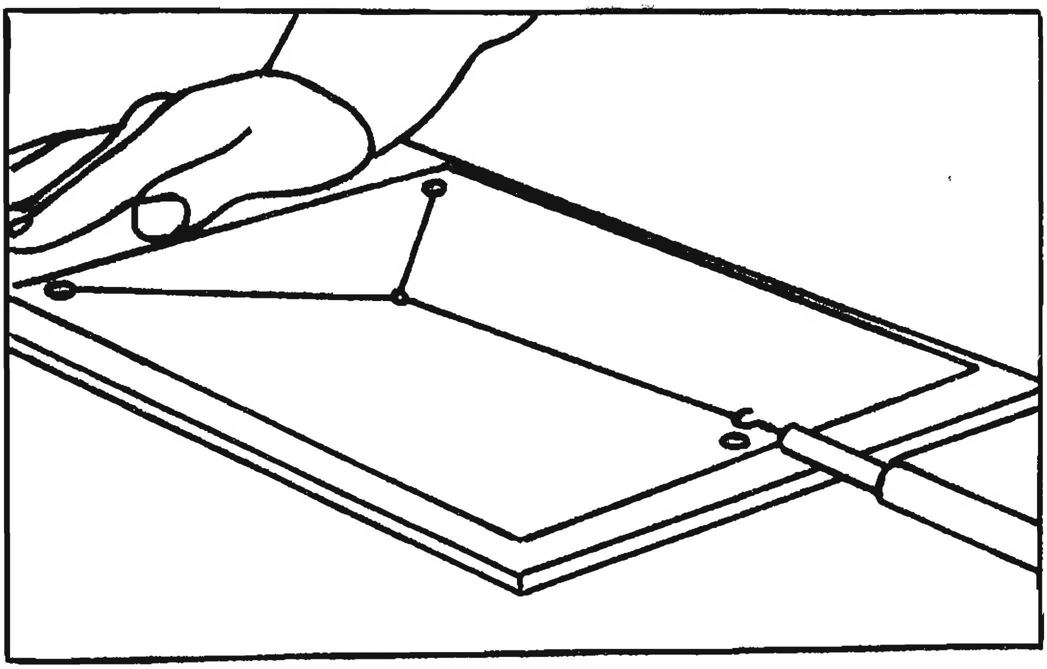
Having done this take one elastic strand, attach it to the end of the spring balance supplied, and extend the strand the distance fixed for the acceleration experiments. With this extension the force exerted on the balance is known. The point to which the balance is extended may be marked accordingly as so many Newtons. The process may be repeated with 2, 3 and 4 strands in parallel, calibrating the balance according to the known force applied. The balance may thus be calibrated completely in Newtons.

(vi) The balance may also be calibrated by simply hanging progressively larger masses from the balance (e.g., 10, 20, . . . to 100 gms in this case). The extension of the spring indicates the force exerted on the mass by the pull of the Earth. It is known that all masses are accelerated towards the Earth at 9.81 meters/sec/sec (g) when free to fall, so that the pull of the Earth on a mass of m kgrms must be mg Newtons. By suspending different masses from the spring the latter can easily be calibrated.

Unfortunately, it is common practice to refer to the force exerted on a mass of m kgrms by the Earth as m kgrms weight instead of mg Newtons, and springs are often calibrated in this way. This is somewhat misleading for the force exerted on a mass of m kgrms by the Earth is not the same as that exerted on the same mass by the Moon.

2.32 Addition of Forces

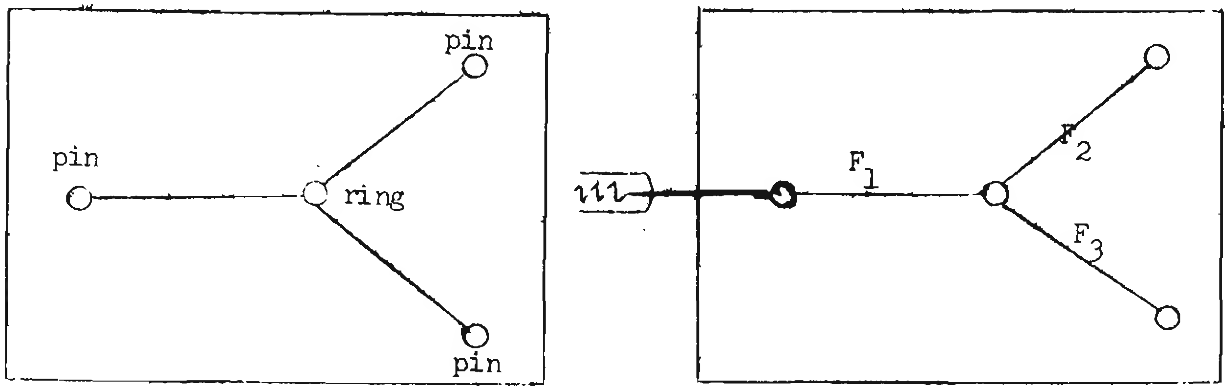
Apparatus Required



Qu	Apparatus	Item No.
1	Relative Motion Frame	1/40/01
1	Spring Balance (1 Newton)	2.10/04
3	Rubber Bands	
3	Thumb Tacks	
1 sheet	Paper	
1	Small Metal Ring	

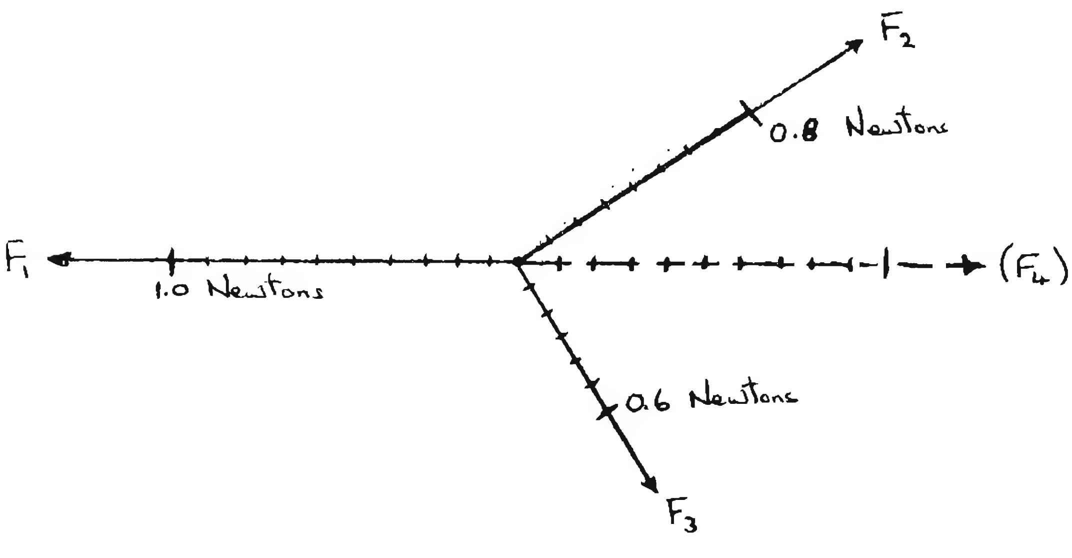
Activities

Take three rubber bands, and fasten one end of each to a small ring, and pin the 3 loose ends to a flat surface (the rear of the relative motion frame) covered by a sheet of clean paper. Each rubber band is about 4 cms long, and should not be stretched more than 4 to 5 cms if it is to behave elastically. If all three bands are extended they will all exert forces on the ring, the forces depending on the extension of the individual bands. Mark the position of the bands on the paper, and then unhook one of the bands,



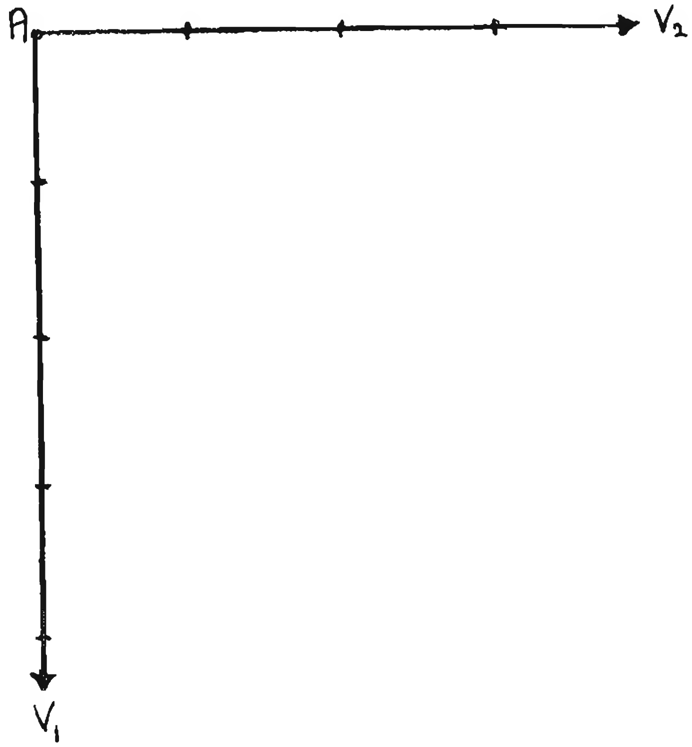
attaching the loose end to a spring balance. By pulling the spring balance, the original balancing position of the bands may be regained. In this position note the force exerted by the balance and hence by the rubber band just replaced. The forces exerted by the other two rubber bands may be determined by a similar procedure.

Now try to analyze the result. Take your sheet of paper indicating the directions of the forces, and mark in the magnitudes (F_1, F_2 and F_3 Newtons)



indicated by the spring balance. You could represent the magnitude of each force on the diagram by the actual extension of the spring balance in each case, or by any simple system of units. Thus 1 cm could represent 0.1 Newtons.

You already know that a single force (F_4) equal and opposite to F_1 could balance F_1. It must therefore follow that F_2 and F_3 could be replaced by a single force (F_4). Study your results carefully. Is it possible that $F_2 + F_3 = F_1$? Can you see any connection between the lines representing F_2, F_3 and (F_4)? One result is far too little to indicate any simple rule of behavior that might exist. It is therefore essential to repeat the experiment 3 or 4 times with the elastic bands exerting different forces at differing angles. In each case carefully analyze the results.



It might help your investigation to consider other examples where quantities cannot be added in the normal way. Thus consider a boy at the point A in a train. The train is moving very slowly at 4 meters/sec in the direction V_1 carrying the boy over the ground. The boy then begins to walk across the train at 3 meters/sec in the direction V_2. One second after beginning to move from A where will the boy be relative to the ground? Taking into account the two types of motion will the boy have moved a resultant distance of 4 + 3 ft? If the train moved for 1 sec and stopped, and then the boy moved for 1 sec and stopped would this have the same resultant effect?

2.40 MASS

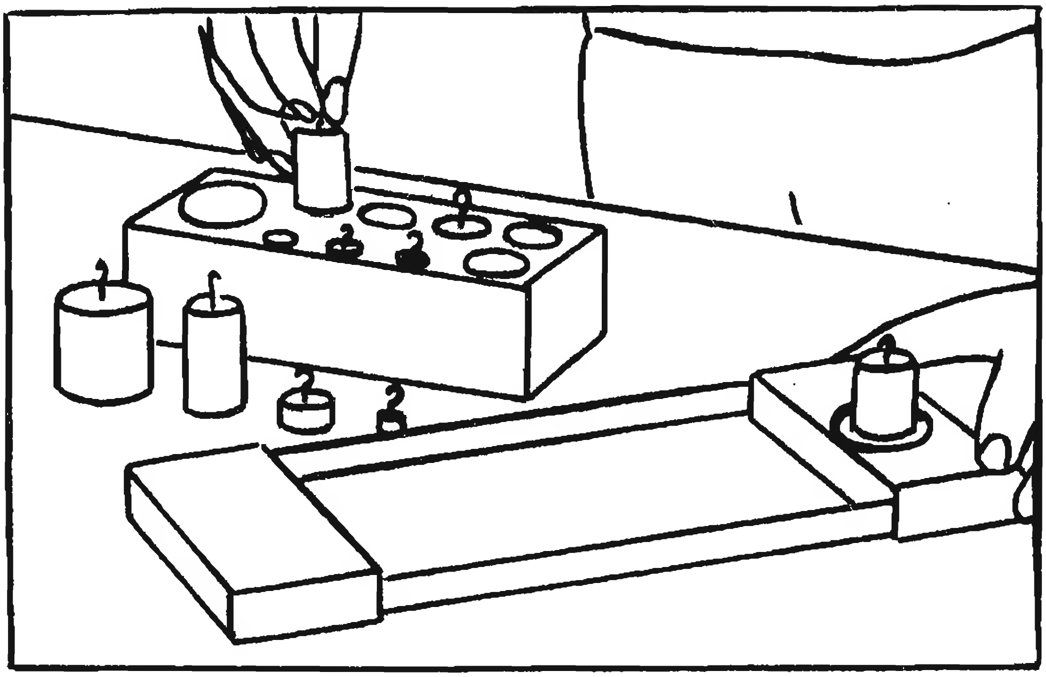
It has already been seen that the spring balance may be used to measure force. In the laboratory it may also be calibrated to measure mass, since the two are related ($F = m.g$). However, the value of 'g' (9.81 meters/sec/sec) varies slightly from place to place on the Earth. On the Moon it is very different (0.163 meters/sec/sec) since the mass of the Moon is much smaller than that of the Earth. It therefore follows that although a given extension of the spring balance always indicates the same force, it does not indicate the same mass extending it, for this also depends on the acceleration due to gravity at that particular point.

Assuming the value of the acceleration due to gravity is not known, but standard masses are available, the simple balance is a better means of determining the mass of a body, since the unknown mass is affected by gravity to the same extent as the standard masses, and the two will balance in the same way, regardless of the location (on the Moon, the Earth, etc.).

With these factors in mind it is of interest to study mass from a point of view of inertia.

2.41 Mass and Inertia

Apparatus Required



Qu	Apparatus	Item No.
1	Inertial Balance	2.40/01
1	Box of Weights (with the 150 gm mass, scotch tape over the 150 marking)	1.20/02
1	C Clamp	2/20/04
1	Chain of Rubber Bands (Approx. 50 cms long)	
1 meter	String	
1	Pendulum Ball (or similar mass)	
1	Metal Strip (15 cms of packing case band)	

Activities

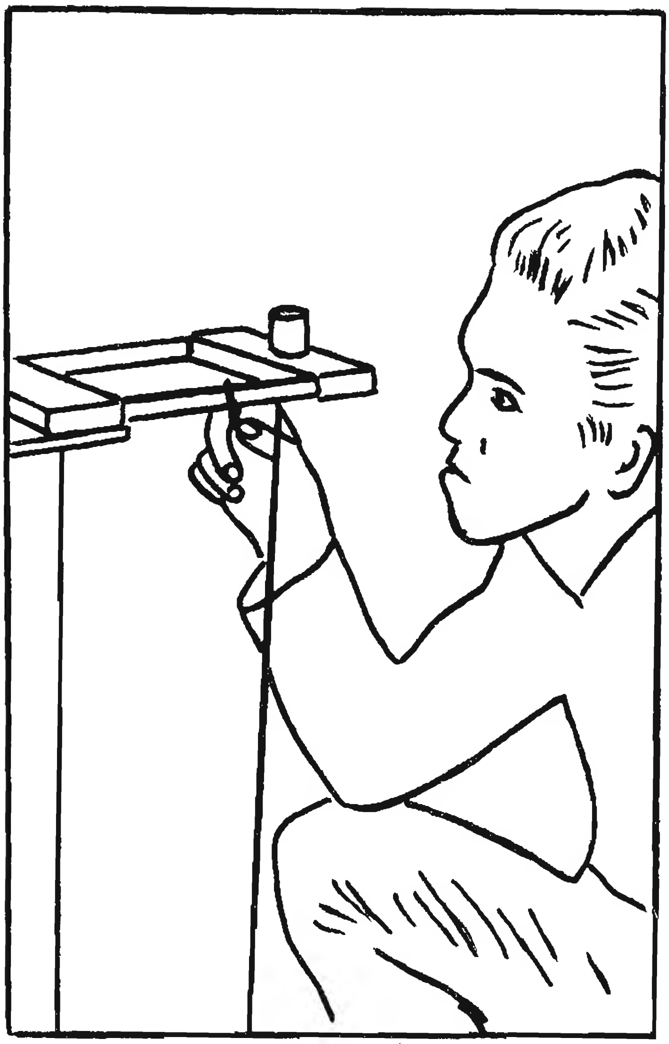
(i) Clamp the inertial balance to the bench so that it can vibrate in a horizontal plane. Set up a simple pendulum (25 cm length of string and a pendulum bob) to serve as a timing device, and set the inertial balance vibrating. Note the time taken for the balance to complete 20 oscillations, and hence determine the period of a single oscillation.

The mass of the platform is known to be 100 gms. Now increase the effective mass of the platform by 100 gms, simply by adding a standard mass. Determine the new period of oscillation. Then repeat the process for additional 100 gm masses up to an effective platform mass of 500 gms. Should the mass on the platform show any tendency to slip as the platform vibrates, secure it by a piece of modeling clay between the mass and platform.

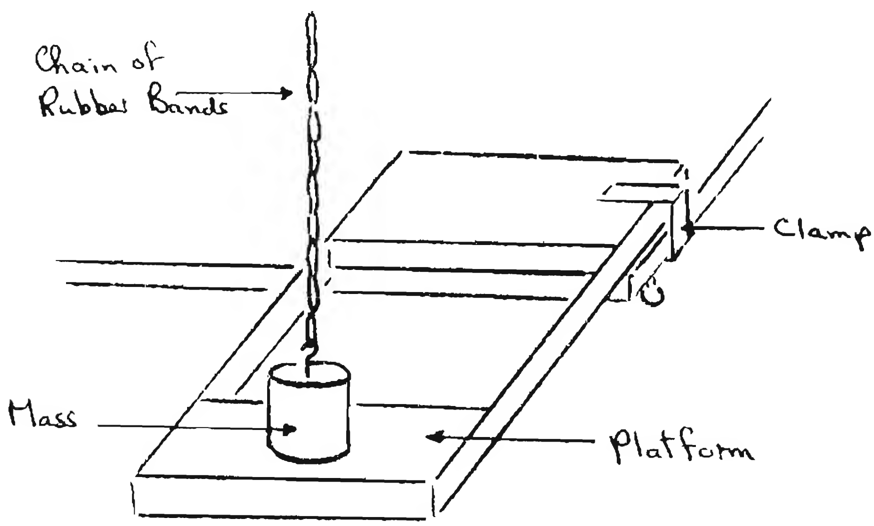
You might have some difficulty counting the most rapid vibrations of the inertial balance, and in that case you will find an additional metal strip most useful. Simply hold the strip in such a way that the balance taps the strip at the extremity of each vibration. It seems much easier to count the vibrations by listening to the taps than by simply using the eyes.

Plot a graph showing how the period of vibration of the platform varies with its effective mass. You are now supplied with an unknown mass. Can you determine its mass by using the inertial balance?

(ii) Adjust the effective mass of the platform to 500 gms. Take the chain of rubber bands available, and attach one end to the mass on the platform. Thread the chain through the hole in the platform, and hold the other end on the floor. This causes the chain to extend, and exerts a downward force on the platform. Set the balance in vibration, and determine the new period of oscillation under the additional force effectively increasing the effect of gravity. Compare the rate of vibrations with that of the same effective mass under normal gravity conditions.



Now replace the downward pull of the chain of rubber bands by a fixed upward pull, thus reducing the effective pull of gravity, and repeat the experiment. What do you note about the resultant rate of vibrations?



2.50 ACTION, REACTION AND MOMENTUM

2.51 Direct Collisions between Carts

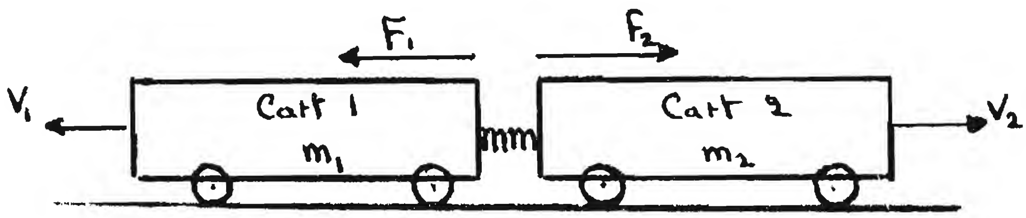
Apparatus Required

Qu.	Apparatus	Item No.
2	Carts	2.20/01-02
1	Box of Weights	1.20/02
1	Ticker Tape Timer	1.30/01
1	C Clamp	2.20/04
1	Needle (3 cms long)	
1	Meter Rule	
1	Chain of Rubber Bands (40 cms long)	
1	Thumb Tack	

Activities

Our observations of action and reaction have been very simple so far. It is now proposed that you study the problem more carefully not only when the bodies are permitted to push one another apart but also when bodies collide one with the other.

(i) Let's introduce our first experiment with a simple theory. Let two carts be placed in contact on a horizontal surface so that by releasing



a spring cart 2 can push cart 1. We can then investigate quite simply whether cart 1 reacts and pushes cart 2. But the main question is whether the forces of action (F_1 on cart 1) and reaction (F_2 on cart 2) are equal and opposite. In considering this, it should be recognized that forces can only act between the carts while they remain in contact through the spring. The carts should thus accelerate for the same period of time while the springs maintain contact, gaining velocities 'v_1' and 'v_2' which would be maintained if friction could be neglected.

Let's see what would happen if the forces of action and reaction are equal and opposite.

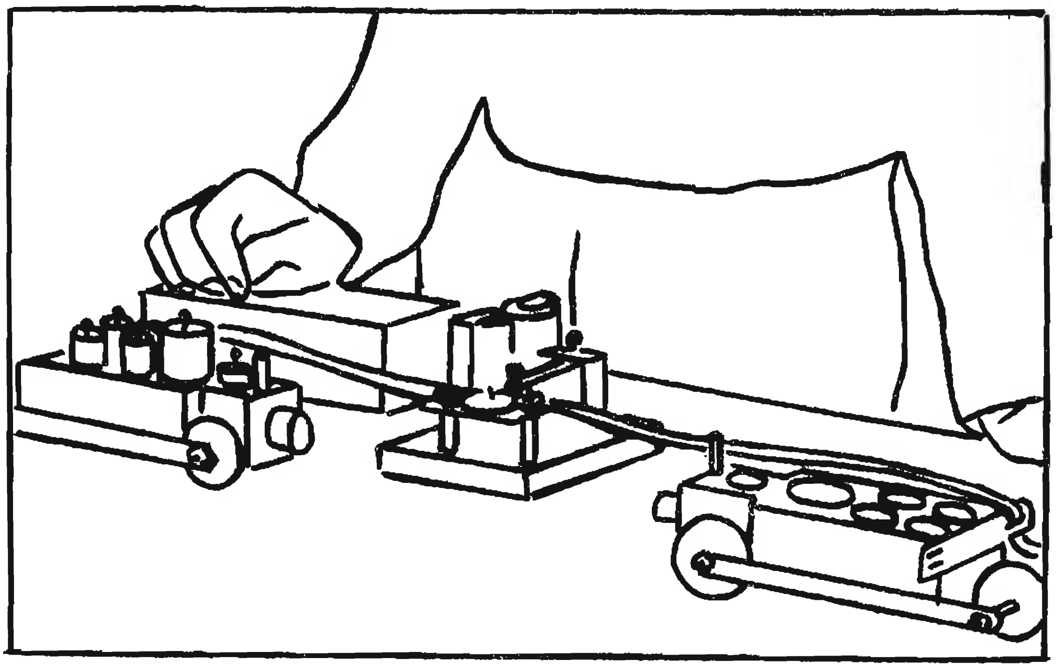
If:

$F_1 = -F_2$	Action is equal and opposite to reaction.
$m_1a_1 = -m_2a_2$	'a_1', and 'a_2' represent the acceleration of each cart while the springs act on one another.
$\dfrac{m_1(v_1 - o)}{t} = \dfrac{-m_2(v_2 - o)}{t}$	The velocities of the carts just before the springs act on one another are zero, but 't' seconds later just as the contact is lost the velocities are 'v_1' and 'v_2'.

Hence:

$m_1v_1 = -m_2v_2$	The quantity 'mv' for a body is called its MOMENTUM.

It therefore follows that if action and reaction are equal and opposite, then the resultant momentum generated in each cart (just after they stop acting on each other) should also be equal and opposite. This should not be difficult to test out.

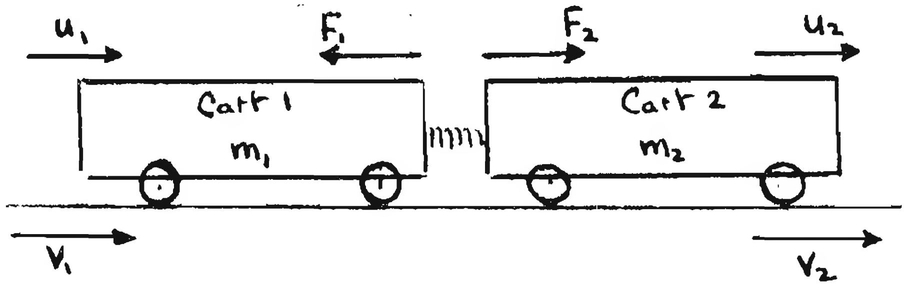


Take two identical carts, and use a ticker tape timer to measure the velocities of the carts when they are driven apart by releasing a spring between the carts. In this experiment it is convenient to attach the ticker tapes to extensions protruding from the carts. Both ticker tapes can pass through the same ticker tape timer so long as two carbon discs are used with the timer, one on top of each ticker tape. Strike the spring release on one cart, so that the spring will push the two carts apart. Measure the length of protruding spring to determine the distance moved by the carts while they were in actual contact. Let's say this is 10 cms. Take the two ticker tapes and mark off on each tape the first 5 cms of recorded motion. According to the ticker tape what are the two carts doing during the short interval of time marked off? After the short interval marked off measure the velocity of each cart, say in cms per 'five tick'.

Repeat the above experiment with the mass of cart 2 doubled and then trebled, keeping that of cart 1 the same throughout. Compare the momentum of each cart after collision.

(ii) The purpose of this activity is to determine if action equals re-action if two carts are in motion at the time that they collide with one another. Once again it is useful to start with a simple theory.

Let's consider the case of two carts moving in the same direction with velocities 'u_1' and 'u_2' so that cart 1 catches cart 2, and a collision results. After the collision the carts continue to move in the same direction, but with different velocities 'v_1' and 'v_2'. During the collision there is an action



force 'F_2' exerted on cart 2 by cart 1, and a reaction force 'F_1' exerted by cart 2 on cart 1. Since motion is present during the collision we might hypothesize that the forces involved are not equal and opposite in this case.

We can test this suggestion out in much the same way as in the foregoing experiment. Let's start again by seeing what would happen if the action and re-action were equal and opposite.

If:

$$F_1 = -F_2$$

$$m_1 a_1 = -m_2 a_2$$

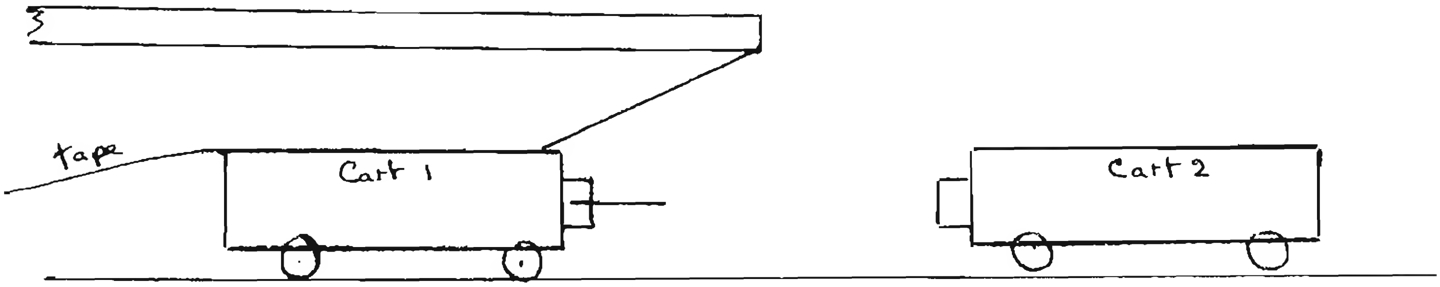
$$\frac{m_1(v_1 - u_1)}{t} = \frac{-m_2(v_2 - u_2)}{t}$$

$$m_1 v_1 - m_1 u_1 = -m_2 v_2 + m_2 u_2$$

or $$m_1 v_1 + m_2 v_2 = m_1 u_1 + m_2 u_2$$

In other words if the action and reaction are equal and opposite during such a collision then the total momentum of the two carts after the collision would be just the same as the total momentum of the two carts before the collision. Once again this finding should not be too difficult to test. All that is needed is to observe the velocities of two carts of known mass, before and after such a collision.

This experiment is simplified by keeping cart 2 stationary prior to the collision ($u_2 = o$), and insuring that both carts move off together with the same velocity ($v_1 = v_2 = v$) after the collision. The latter may be realized by inserting a needle into the stopper of cart 1, so that this sticks into the stopper of cart 2 on collision, thus binding the two carts together.



Your investigation will be simplified if you can make a check on your interpretation of the motion on the ticker tape. Note the initial separation of the two carts. Then use a ruler and chain of elastic bands to create the initial velocity of the cart (over say a distance of 15 cms) so that the distance accelerated by the cart, prior to it achieving a constant velocity is known.

Pass a ticker tape through the timer and attach it to cart 1. This will provide all the records you require. Accelerate cart 1 over a distance of say 15 cms with the meter ruler and chain of elastic bands, insuring that cart 1 collides with cart 2 in such a way that they move off together after collision. Take the resultant ticker tape track and mark off the portions which represent the initial acceleration of cart 1, the constant motion of cart 1 just prior to collision, the collision itself (a distance equivalent to the distance the needle penetrates the stopper), and the constant motion of the two carts after collision. Determine the velocity of cart 1 (u_1) just prior to collision, and that of both carts (v) just after collision in cms/'five tick'.

Repeat the experiment with the mass of cart 1 doubled, while that of cart 2 remains constant. Compare the total momentum of the carts before and after collision in each case remembering that we are concerned to determine whether the following equation holds:

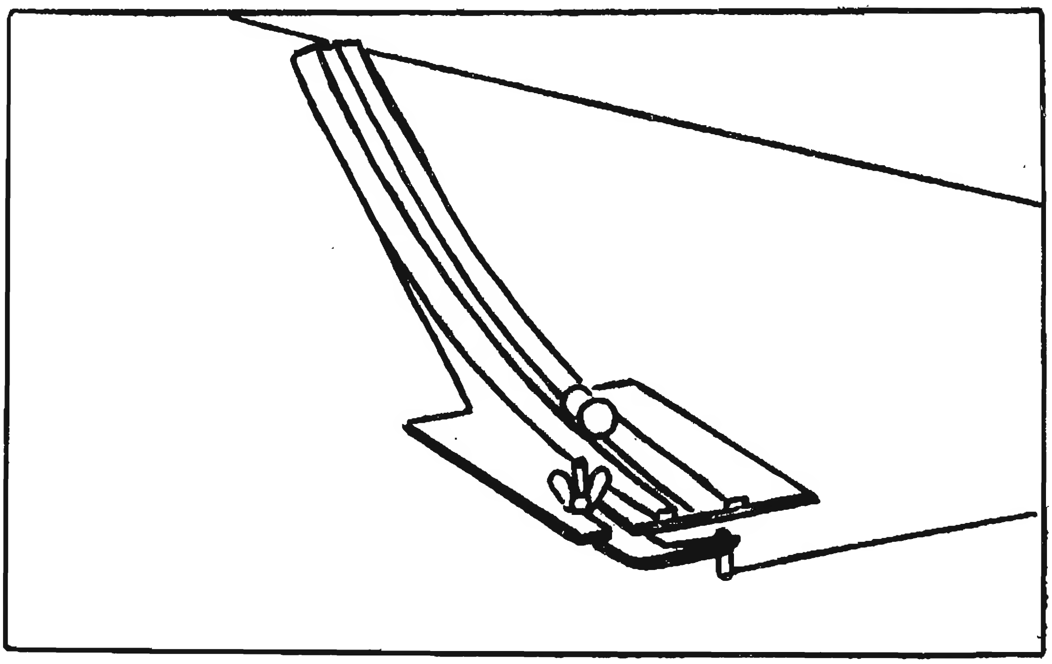
$$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

or $(m_1 + m_2)v = m_1u_1$ since $v_1 = v_2 = v$ after collision, and $u_2 = o$ before collision.

Can you indicate whether or not action equals reaction during these collisions?

2.52 Direct and Indirect Collisions between Ball Bearings

Apparatus Required

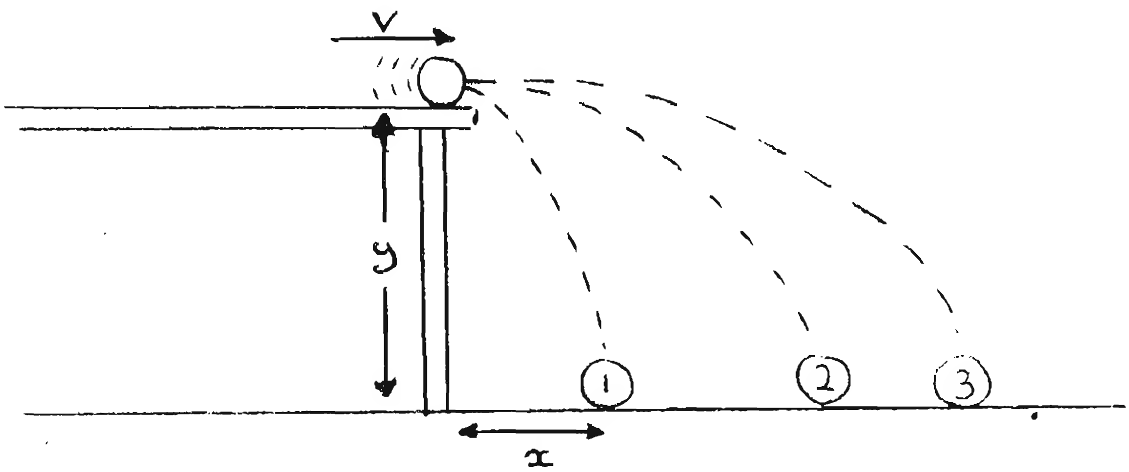


Qu	Apparatus	Item No.
1	Elastic Collision Runway	2.50/01
1	C Clamp	2.20/04
2	Ball Bearings (2.4 cm diameter preferred, but 1.2 cm is possible)	
1	Meter Rule	

Activities

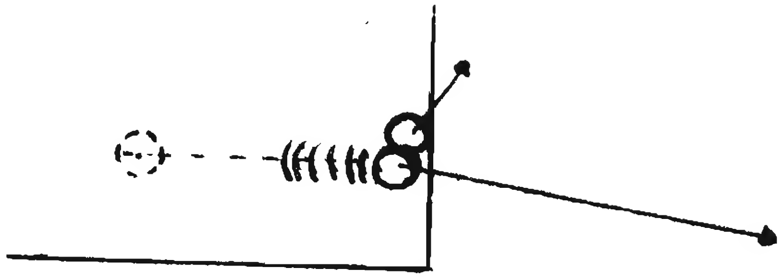
In the foregoing experiment we investigated the behavior of two carts during an inelastic collision where the carts stuck together after impact. The experiment might well have been repeated with an elastic collision in which the cart springs separated the carts after collision. Elastic collisions can be equally well investigated using ball bearings, and these will be used in the following investigations.

(i) The first activity is simply intended to highlight the properties of ball bearings in flight, so that the subsequent activities involving collisions of ball bearings may be investigated by analyzing the flight paths of ball bearings after collision.



The teacher will take a steel ball bearing, and roll it across the table at varying speeds so that it rolls off the table with differing horizontal velocities 'v'. How does the distance 'x' travelled across the floor depend on the horizontal velocity of projection from the table? Does the time taken for the ball to reach the ground depend on the distance 'x' travelled horizontally? To answer this question more realistically the teacher will place one ball bearing on the very edge of the table, and will roll another ball bearing across the table so as to create a glancing collision at the edge. Both balls will leave the table simultaneously, but at different speeds, and the distances travelled across the floor will differ. Listen very care-

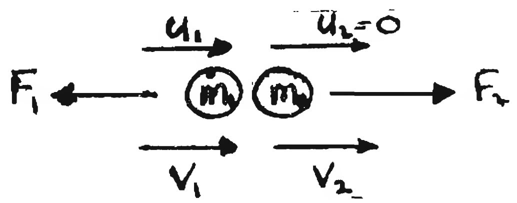
fully for the clicks as the balls hit the ground. Which ball hits the ground first, the one leaving the table with the greatest horizontal velocity or the other?



The teacher will now show you how you can determine the velocity of any ball leaving the table top, so long as you measure the height 'y' of the table and the distance 'x' the ball travels horizontally before striking the ground, simply by substituting in the equation below.

$$v = x\sqrt{\frac{g}{2y}} \quad (g = \text{acceleration due to gravity})$$

(ii) It is now our intention to use our newly found knowledge to investigate whether action and reaction are equal and opposite, or not, when a direct elastic collision occurs between two steel balls. Let's start out with the hypothesis that action and reaction will be equal in such a collision. We may thus derive a simple relation between the motions of the balls, and test this out.



Consider two identical steel ball bearings (each of mass m), one travelling with a velocity 'u_1', towards the other which is stationary (u_2 = o). A direct collision occurs and the two balls move along the same path after collision with velocities 'v_1' and 'v_2'.

As before it can be shown that if action and reaction are equal and opposite

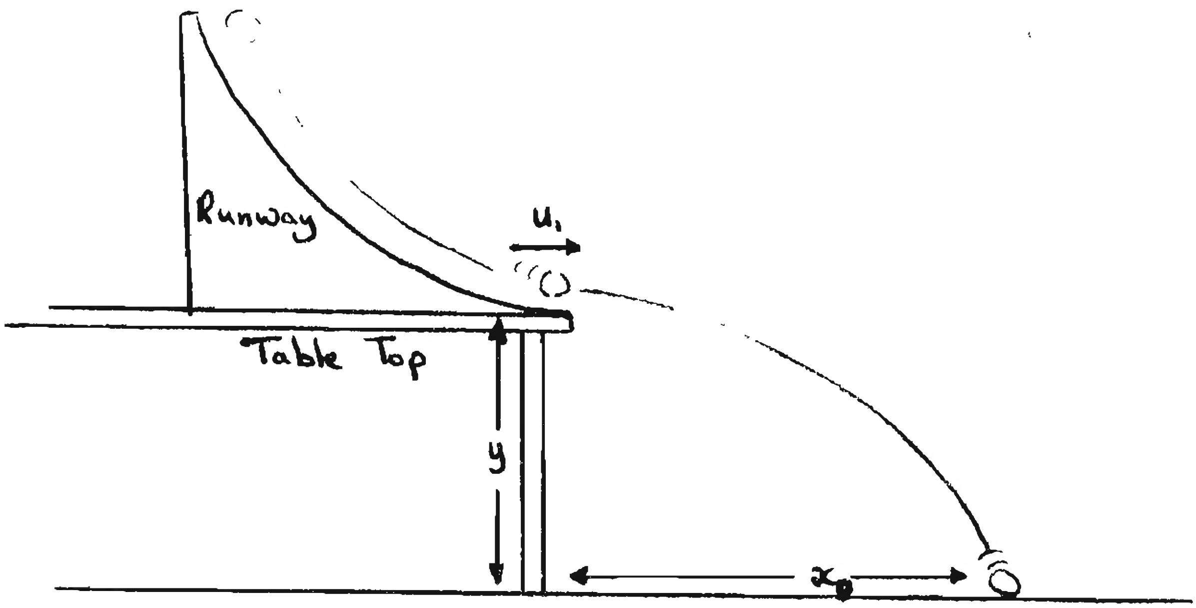
$$F_1 = -F_2$$

$$ma_1 = -ma_2$$

$$m(v_1 - u_1) = -m(v_2 - o)$$

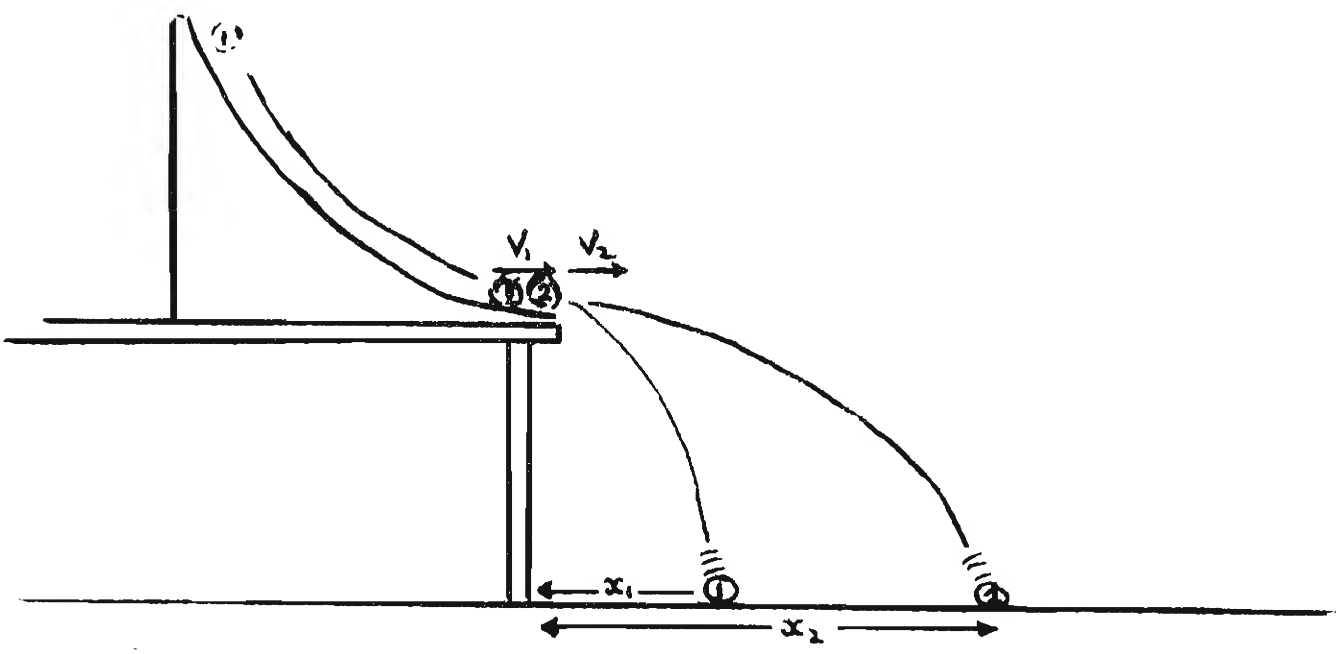
$$\text{or} \quad v_1 + v_2 = u_1 \quad \text{———} \quad (1)$$

Such a collision could be created by means of a simple runway. If one ball is rolled down the runway from the top it will always reach the bottom of the runway with the same horizontal velocity 'u_1' which can be determined from the distance 'x_o' it travels horizontally before striking the ground, and from the height 'y' of the table.



$$u_1 = x_o\sqrt{\frac{g}{2y}} \qquad (2)$$

Now imagine an identical ball placed at the bottom of the runway. If the first ball is released once more from the top it will strike the stationary ball with a velocity 'u_1' which we have already calculated. After the collision the two balls will move off with horizontal velocities 'v_1' and 'v_2' which can again be determined from the horizontal distances 'x_1' and 'x_2' respectively which they travel before striking the ground.



$$v_1 = x_1\sqrt{\frac{g}{2y}} \quad \text{———} \; ③$$

$$v_2 = x_2\sqrt{\frac{g}{2y}} \quad \text{———} \; ④$$

If equation 1 is true:

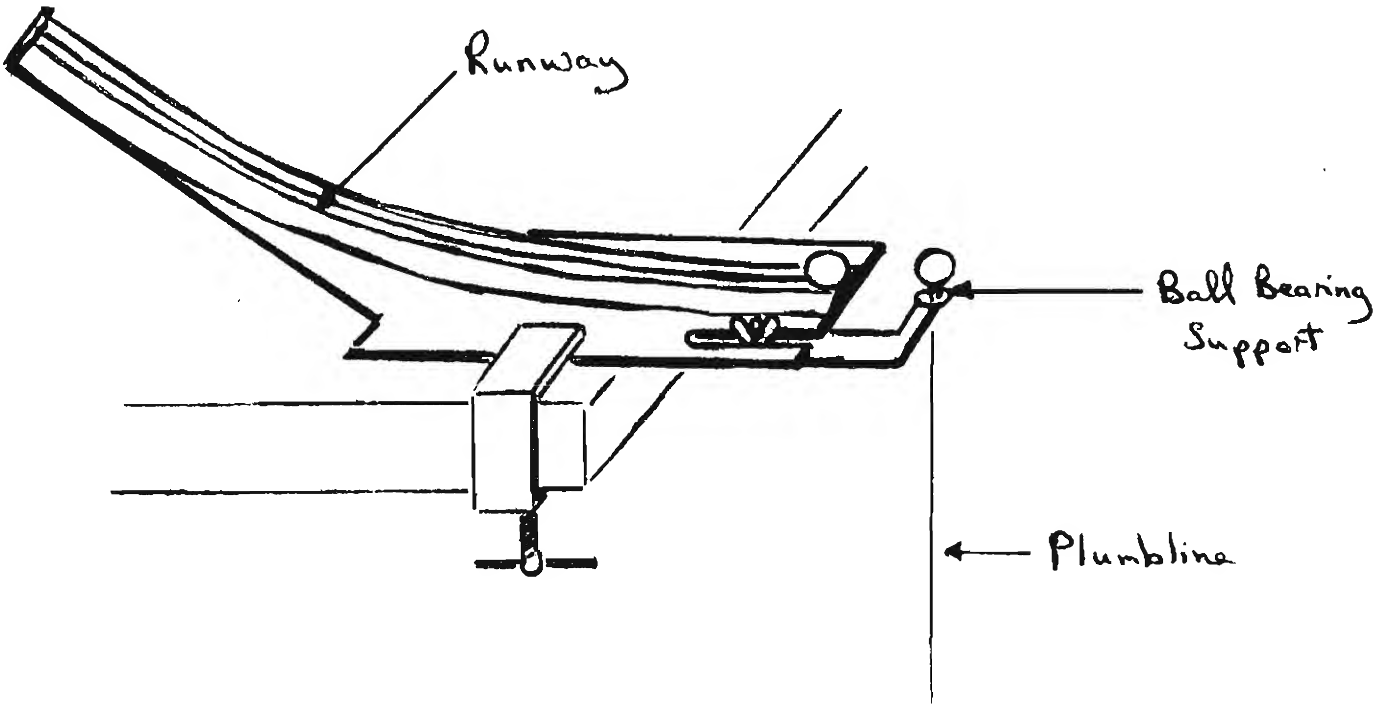
$$v_1 + v_2 = u_1$$

It follows by substituting for the velocities from equations ②, ③ and ④ that:

$$x_1\sqrt{\frac{g}{2y}} + x_2\sqrt{\frac{g}{2y}} = x_o\sqrt{\frac{g}{2y}}$$

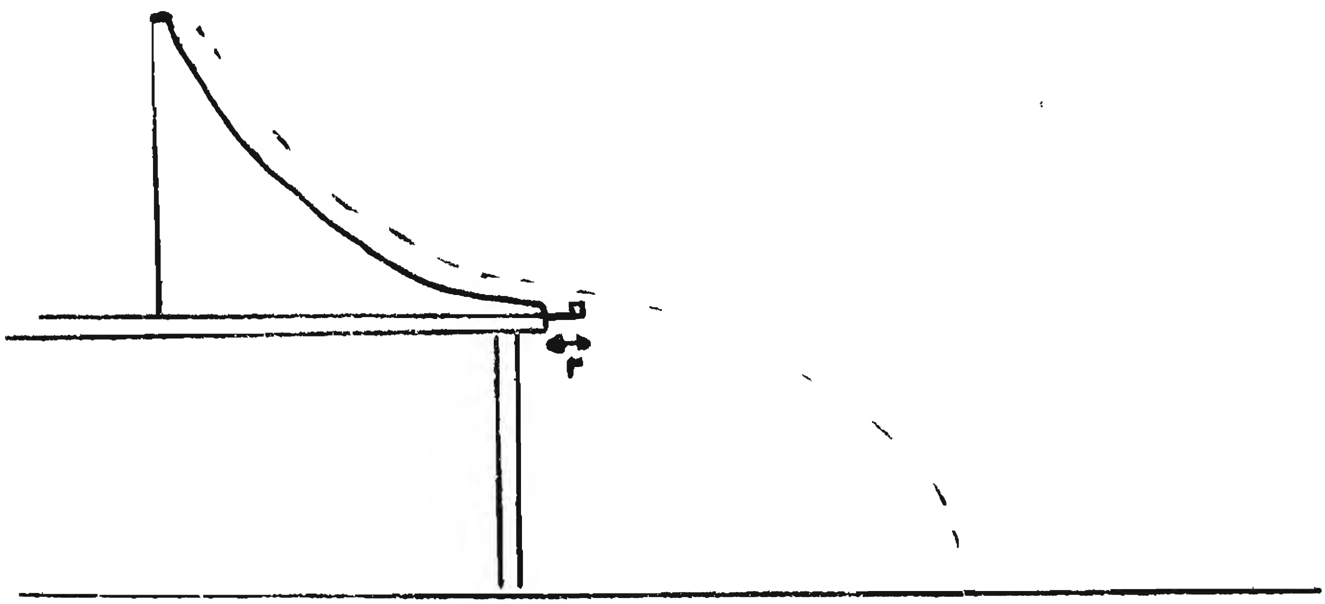
or $$\boxed{x_1 + x_2 = x_o}$$

If experiment shows the above relationship to be true then it must follow that in such an elastic collision of two balls that action and reaction are equal and opposite. You are now ready to test out your hypothesis.

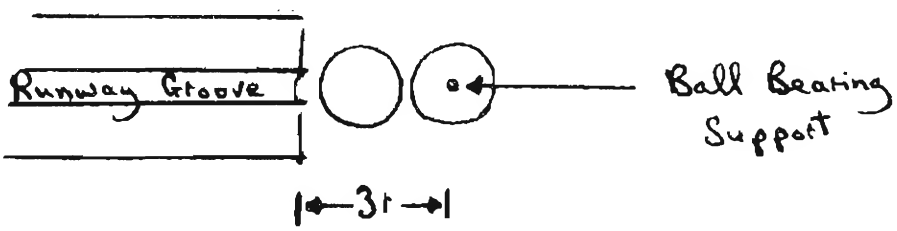


Clamp the runway to the bench. Place a sheet of plain paper, covered by carbon paper, on the floor to record the points of impact. Push the ball bearing support to one side, and roll a ball bearing down the slope from the very top in order to determine its free flight x_o.

Then arrange for a direct collision between the two balls. A few careful adjustments are necessary. If 'r' represents the radius of either ball, place the ball bearing support in the direct path of the ball bearing,

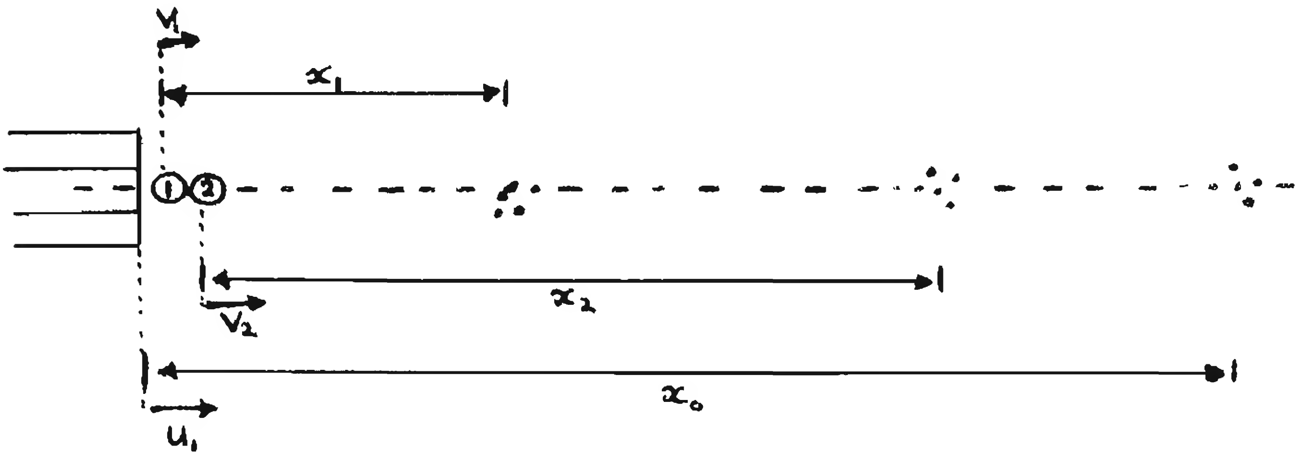


at a distance 'r' from the end of the runway. Then adjust the height of the support so that when the ball is released from the top of the runway it only just clears the top of the support. Then with the support at the same height move it so that it is directly in line with the center of the runway groove, but at a distance '3r' from the end. The reason for these adjustments will become clear once you perform the experiment.



Now place one of the balls on top of the support, and release the other from the top of the runway. Note the resultant flights 'x_1' and 'x_2' of the two balls. All observations should be repeated 4 or 5 times to obtain an average flight distance.

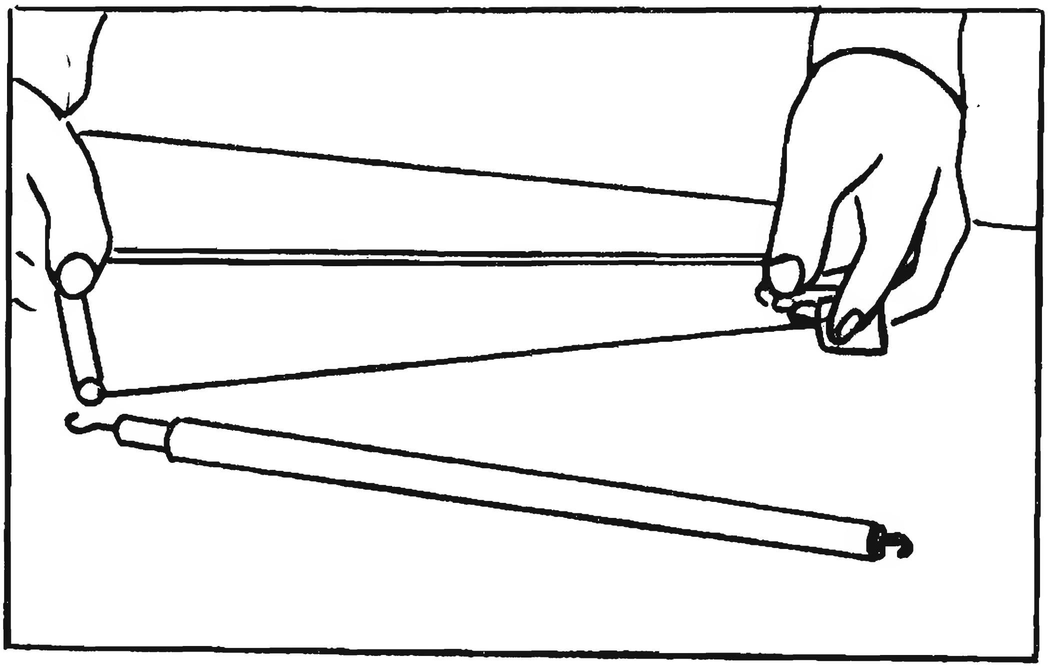
Finally to help measure the appropriate distances accurately, suspend a plumb line from the bottom of the screw. It is then possible to record not only the points of impact, but also the positions vertically beneath the support and the end of the groove, and hence the exact flights of the balls after collision. Having measured these distances, noting the possible variation in the values, do you conclude from this experiment that action and reaction are equal and opposite during the collision?



2.60 CIRCULAR MOTION

2.61 Centripetal Force

Apparatus Required



Qu.	Apparatus	Item No.
1	Centripetal Force Apparatus	2.60/01
1	Spring Balance (1 Newton)	2.10/04

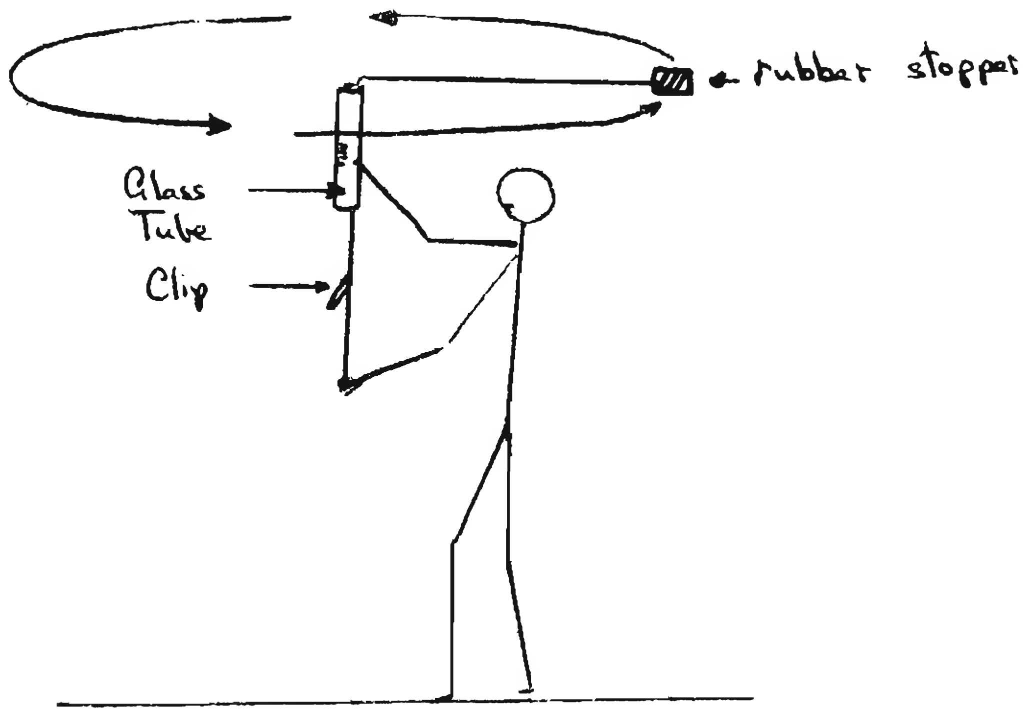
Activities

(i) It is useful to introduce this topic with a little mental activity by considering what appear to be two conflicting forms of evidence.

Consider the motion of the Moon about the Earth or that of the Planets about the Sun. Would you feel inclined to suggest that circular orbits are a natural form of motion in the Universe?

Now consider yourself travelling on a speeding bus on a rough twisting mountain road. The passengers' luggage is loosely fastened on the roof, and is in danger of coming off any minute. The bus moves into a sharp left hand bend far too fast. You believe your baggage is going to fall off the roof. In which direction would you look to check whether this happens? If the driver suddenly realized that he was travelling far too fast and applied his brakes very sharply, would you expect the loose packages to be thrown forward in such a way as to follow the curve of the road or to be thrown forward in a straight line? Does this mental evidence suggest that circular paths are a natural form of motion on Earth? It is of interest to investigate this problem a little more scientifically.

(ii)



Take the centripetal force apparatus and attach the string through the glass tube to a rubber stopper at one end and a small finger at the other.

Whirl the stopper round a circle keeping the radius constant at about 30 cms. A clip attached to the string is very useful in assessing the radius of motion.

As the stopper whirls around how is your finger affected? What would happen if you removed your finger from the string or cut the string? (Don't do this unless you are out in the open.) Can you summarize your observations by indicating what physical factor is essential to provide circular motion?

We have already noted that many bodies in the universe follow approximately circular orbits. Compare the motion of such bodies with that of the rotating stopper, and draw whatever comparisons you can.

(iii) Let's investigate circular motion a little more carefully trying to discover some sort of relation between a centripetal force and the motion involved. The first series of observations should simply give crude indications of the possible relationship, while the final observations should give a more exact indication.

Take the same apparatus as before. Fix the radius of the motion at about 30 cms, and whirl the stopper slowly around a circular path. Notice the force exerted by your finger on the string, then rapidly increase the rate of rotation. Do you note any change in the force exerted by your finger?

Remove the stopper from the string, replacing it by a paper clip. Repeat the above activity, and note whether the centripetal force involved is affected by the change in mass.

Finally, fasten the rubber stopper back on the string and produce a fairly slow motion with a radius of about 10 cms. Keep the rate of rotation constant (tapping with your foot helps),and increase the radius of motion to about 40 or 50 cms. Is the centripetal force exerted by the finger the same for both radii of rotation?

(iv) It is now proposed that the above activity be repeated taking more exact records of what happens in an attempt to develop a simple relationship between the centripetal force 'F' exerted on the body and the rate of rotation (in revolutions per minute).

Set up a circular motion of the rubber stopper once again, keeping the radius of motion constant at 50 cms. Count the number of revolutions of the

stopper per minute, and note the corresponding centripetal force in Newtons. Repeat the experiment with the same stopper, the same radius of rotation, but different rates of rotation.

Relationships in physics are usually fairly simple, and there is a good chance that one of those listed below will describe the behavior of the motion. Without doing any detailed calculations could you propose any one of the relationships as being more suitable than the others.

$$F \propto n \qquad F \propto \frac{1}{n}$$

$$F \propto n^2 \qquad F \propto \frac{1}{n^2}$$

Finally, it has already been noted that when a mass is subjected to a force it accelerates. It must therefore follow that a body following a circular path at constant speed is accelerating. Wherever there is acceleration there is a change in velocity, and yet in this case we believe that the body rotates at a constant speed. Can you explain this?

2.70 WORK AND ENERGY

2.71 Energy Transfer

Qu.	Apparatus	Item No.
1	Lead Strip (Approximately 10 x 5 x 0.1 cms)	
1	Hammer	
1	Nail (10 cms long, 0.7 cms diameter)	
1	Hacksaw	
1	Dynamo/Motor	2.70/01-02
1	Bulb Holder with Bulb	5.10/02
1	Switch	5.10/03

Activities

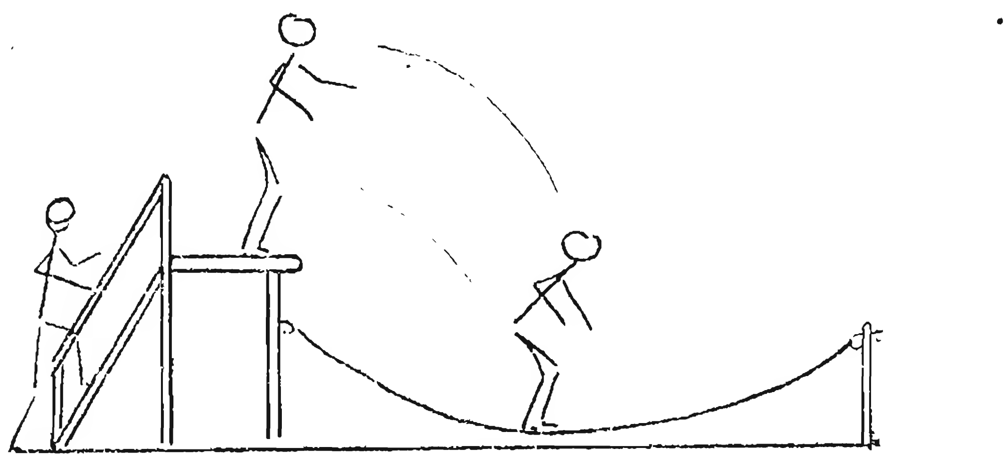
(i) Before we undertake any specific experiment about energy it is useful to consider in our own minds what we normally mean by the word energy. Let's give the question some consideration.

In order to do work, to run or climb, you require energy. This comes from "food energy" in the body. If you do not eat you lose energy. Food is essential if "bodily energy" is to be maintained.

Just in the same way that people require energy to do work, machines also require energy to move about, to climb hills, and in general to do work. This energy comes from "fuel energy" such as gas in cars.

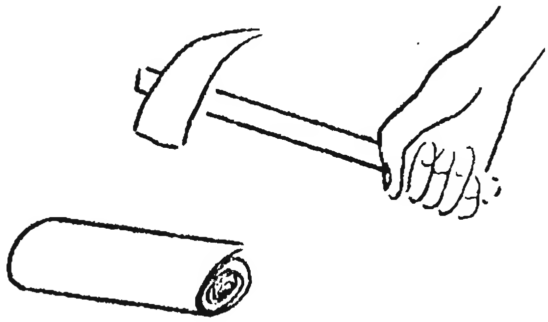
Let's now consider a young boy climbing a hill. In order to climb the hill he requires energy which comes from "food energy". When he reaches the top of the hill he will probably be exhausted, having used up all his "food energy".

Let's imagine the hill is covered in snow. The young boy puts on a pair of skis, and swoops down the hill. Isn't energy normally required to produce motion? If so where does it come from if the boy used up all his energy in climbing the hill?



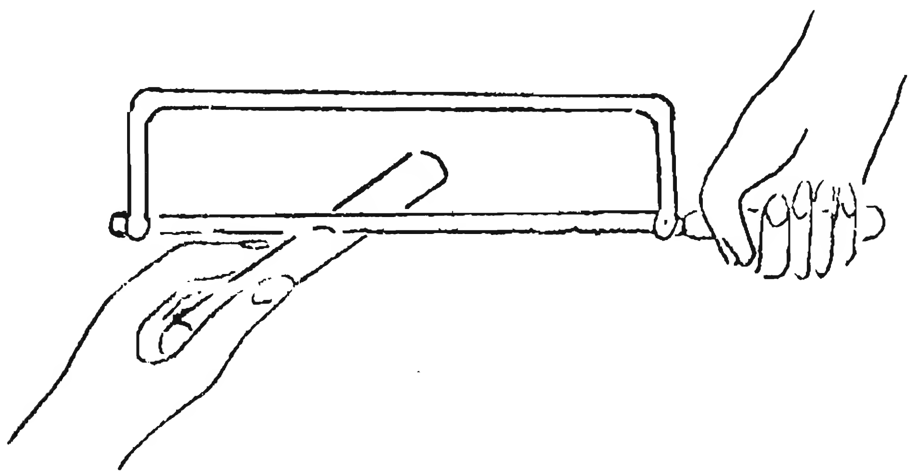
The young boy is a keen athlete, and a little later is found exercising in a gymnasium. He climbs a few steps on to a platform gaining "hill energy" from "bodily energy". He jumps off the platform, thus losing his "hill energy", but gaining "motion energy". His fall is broken by a trampolene which stretches under the impact, and actually halts the motion of the boy before throwing him back into the air. When the boy's downward motion is temporarily halted he has no "motion energy". Where has it gone?

(ii) A strip of lead sheeting is rolled into a very tight cylindrical chape (approximately 2 cms in diameter and 5 cms long). Place the roll on a firm flat surface, and hammer one end completely flat. Place your fingers

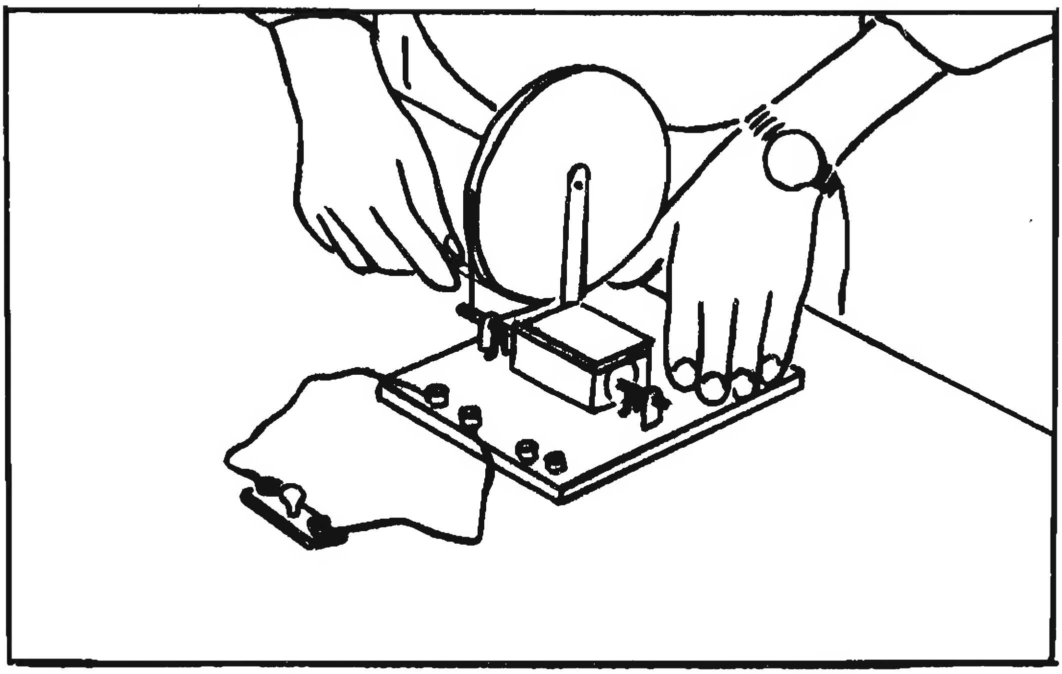


on the flattened lead surface. What do you notice? Clearly some of the "motion energy" of the hammer is used up in deforming the lead. Can you identify any other form of energy which emerges from the "motion energy"?

Somewhat similar observations may be made in cutting through a thick nail with a hacksaw. Cut through a nail and then place your finger on the cut edge. It would seem that "bodily energy" is converted to "motion energy"



which in turn produces "cutting energy", the greater the "bodily energy" used (i.e., the harder one presses with the hacksaw) the greater the resulting "cutting energy". Is any other form of energy derived from the"motion energy"?



(iii) The dynamo provided is connected to a small light bulb by means of a circuit containing a switch. If the switch is in the open position the bulb will not light when the dyanmo is turned by hand. Place the switch in the open position, and turn the dynamo as rapidly as possible by hand. Without stopping push the switch to the on position. The bulb will light up. What else do you notice? Explain this.

2.72 Measurement of Energy and Power

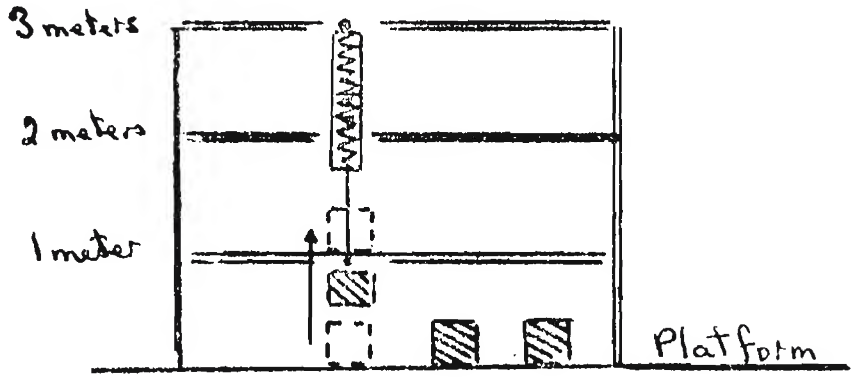
Apparatus Required

Qu.	Apparatus	Item No.
1	Flight of Steps	
1 meter	String	
1	Mass (50 gm)	

Activities

(i) We have already seen that energy is readily transformed from one form to another, and it follows that it would be useful to be able to measure how much energy is transformed at any given time. One way of doing this is by relating energy to work.

Let's imagine that we have 3 masses, each weighing 1 kgm, and 3 shelves at heights of 1, 2 and 3 meters above a platform. If a spring



balance was used to lift any one of the masses slowly upward from the platform, the balance would indicate that a minimum force of 1 g Newtons would be required to lift the mass. We might define the work done in lifting one of the 1 kgm masses vertically through 1 meter as being equal to 1 g Newton Meters or as 1 g Joules.

In order to lift three similar masses (1 kgm each) from the platform to the first shelf it follows that 3 g Joules of work must be done. Equally well, if a 3 kgm mass is lifted through a height of 1 meter on to the first platform it also follows that the work done would be 3 g Joules.

(g = acceleration due to gravity
= 9.81 meters/sec/sec)

If a 1 kgm mass is lifted from the table on to the first shelf, then to the second, and finally to the third, each time it is lifted 1 g Joules of work is required. In lifting the mass through 3 meters to the top shelf 3 g Joules of work is done. This is the same amount of work that is required to lift a 3 kgm mass through 1 meter. This would suggest that we might generally

indicate the amount of work done (W Joules) in raising a body of mass 'm' kgms through a distance of 'x' meters as being:

$$\underset{\text{Joules}}{W} = \underset{\text{Newtons}}{F} \cdot \underset{\text{Meters}}{x}$$

$$= mg \cdot x$$

Such work is a measure of the energy being transferred, say from "bodily energy" to "hill energy".

Look around your school for a long flight of steps, containing say 20 or 30 steps or more. Measure the height of one step, and hence determine the total height of say 20 steps.

Note your own weight, and thus calculate the work you would have to do to lift your own body up the 20 steps.

(ii) Get your friend to join you with some form of timing device. A simple pendulum made from a 50 gm mass and a length of string (such that the distance from the pivot to the center of the mass is 25 cms) will serve the purpose well. Get him to time you while you see how rapidly you can run up the flight of steps. What is the maximum rate at which you can climb? Let your friend repeat the experiment while you do the timing.

Calculate the maximum rate of working which you and your friend can achieve with your legs. You will probably wish to convert your answer to the commonly recognized form of horse power or kilowatts, and the following definitions will be required:

A rate of work of 1 Joule/sec = 1 Watt
1000 Watts = 1 Kilowatt
746 Watts = 1 Horse Power

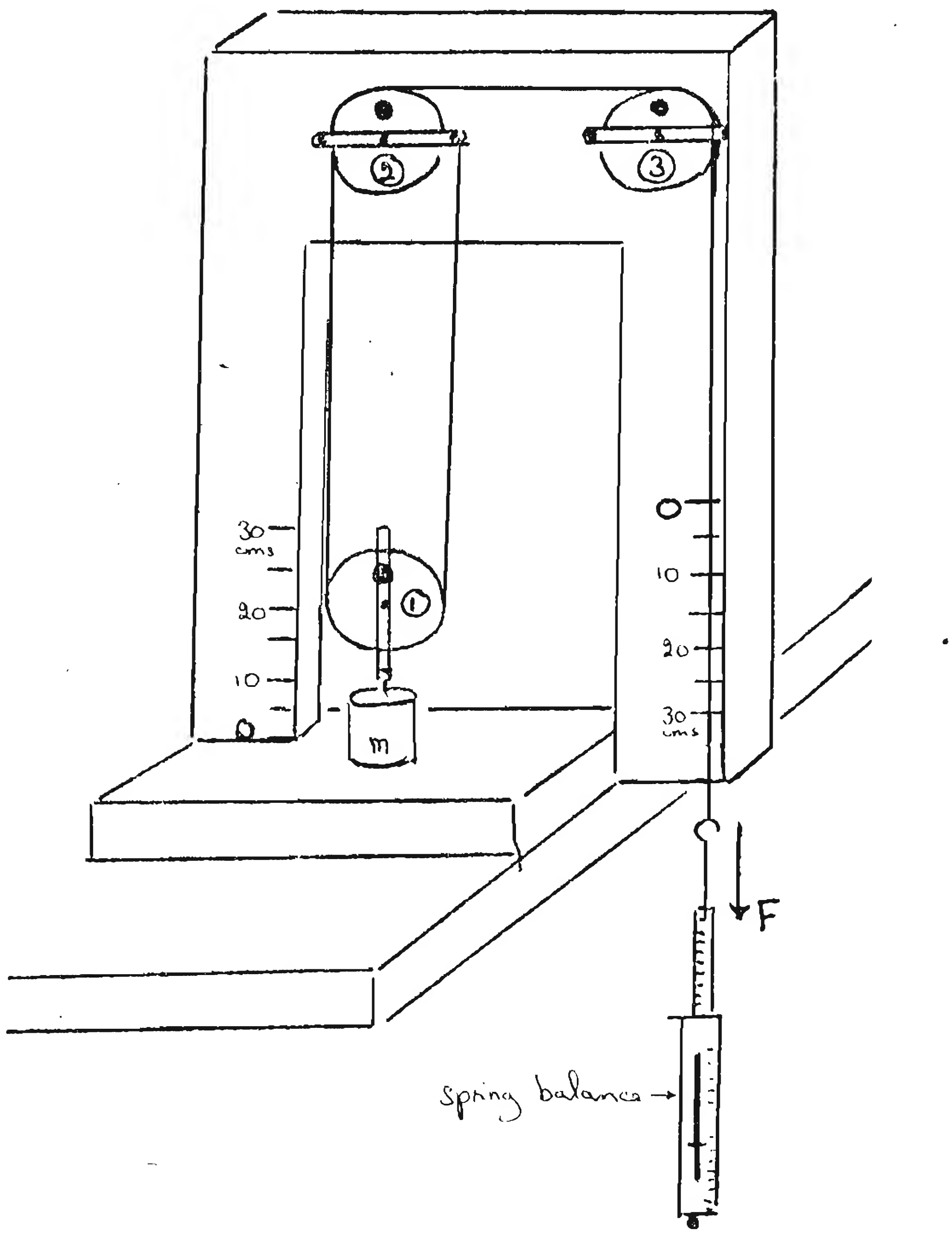
2.73 Efficiency

Apparatus Required

Qu.	Apparatus	Item No.
1	Simple Machine	2.70/03
1	Mass (100 gms)	
1	Spring Balance (1 Newton)	2.10/04

Activities

(i) Is it possible to design a machine in such a way that it is possible to obtain more work out of the machine than the work that is put into it? The simple machine provided is intended to help you investigate this question.



The machine is simply a pulley device designed to lift a mass 'm' with a small applied force 'F'. Each of the three pulleys in the machine may be "jammed" by means of a metal rod inserted through the pulley wheel. With all 3 wheels "jammed" the mass 'm' may still be lifted, but the force 'F' required to overcome friction, and lift the mass is much greater than when none of the wheels are "jammed".

If the mass 'm' (100 gms) was lifted directly through 30 cms the work required to lift the mass would be equal to 'mg.h' Joules, where 'm' is 0.1 kgms and 'h' is 0.3 meters. This is in fact the work got out of the machine, and is called the "Output".

$$\begin{aligned}\text{Output} &= mg.h \\ &= 0.1 \times g \times 0.3 \text{ Joules} \\ &= 0.03\, g \text{ Joules (where } g = 9.81) \\ &= 0.29 \text{ Joules}\end{aligned}$$

With all three wheels moving freely, raise the mass 'm' through 30 cms by pulling steadily on the spring balance. Notice the minimum force that may be exerted by the spring balance and raise the mass. Also note the distance through which the spring balance must move in order to raise the mass 30 cms.

If the force exerted by the spring balance is 'F' Newtons, and this must be moved through 's' meters, the work done by the force 'F' must equal 'F.s' Joules. This is called the "input" into the machine.

$$\text{Input} = F.s \text{ Joules}$$

Repeat this experiment 3 more times, once with all 3 wheels jammed, then with two wheels jammed, and finally with 1 wheel jammed. In each instance determine the "Input" into the machine. Is the "Input" ever less than the "Output"?

If the "Efficiency" of the machine is defined as follows:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

what would appear to be the maximum efficiency that you might expect to get out of the machine?

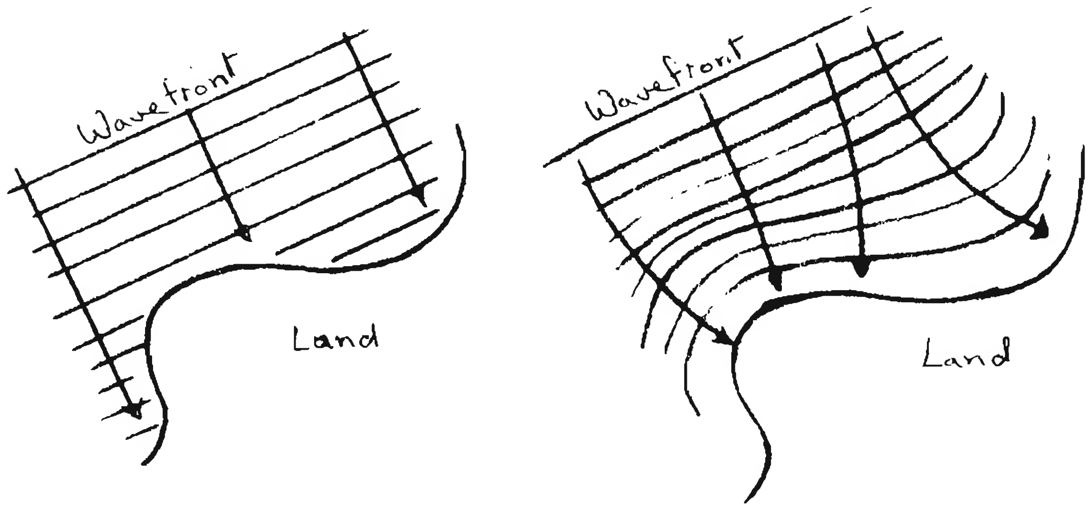
2.80 IN PERSPECTIVE

In studying forces and their effects on a small scale in the laboratory we should not lose track of the magnitude of forces in real life. One can only guess at the size of some of the forces enclosed within the Earth's Crust, but we may obtain some indication of the order of magnitude of these forces from subsequent earthquakes and volcanic eruptions.

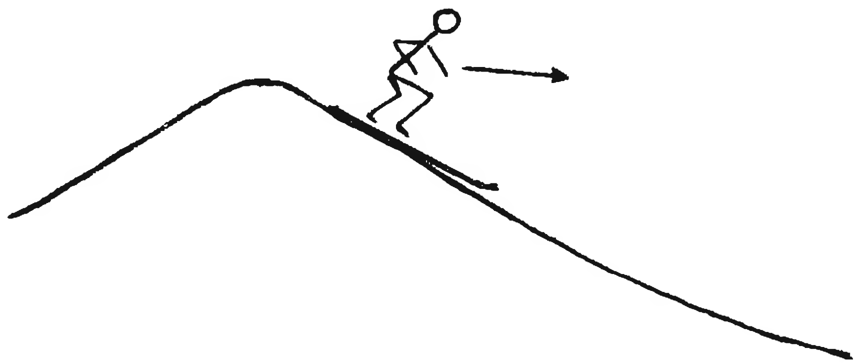
We might quote here the eruption of Krakatoa in 1883. Krakatoa is an island in the Sundra Straits between Java and Sumatra. When it erupted 57,000 million cubic meters of rock were flung into the air changing a 900 meter high mountain into a 300 meter deep crater. 2,700 kilometers away in Australia the eruption sounded like artillery fire, while the noise of the explosion was even recorded 4,800 kilometers away on Rodriguez Island, near Madagascar. Tidal waves over 17 meters high were created in the vicinity of the volcano, and these, after travelling over 8,000 kilometers, were recorded in Cape Town as being almost half a meter high. Although there were no large towns within 150 kilometers of the volcano 36,000 people lost their lives. It is sobering to realize that in comparison, in the atomic explosions that devastated Hiroshima and Nagasaki, peopl little over 30 kilometers from the centers of devastation were unaware of the explosions.

3. WAVE MOTION

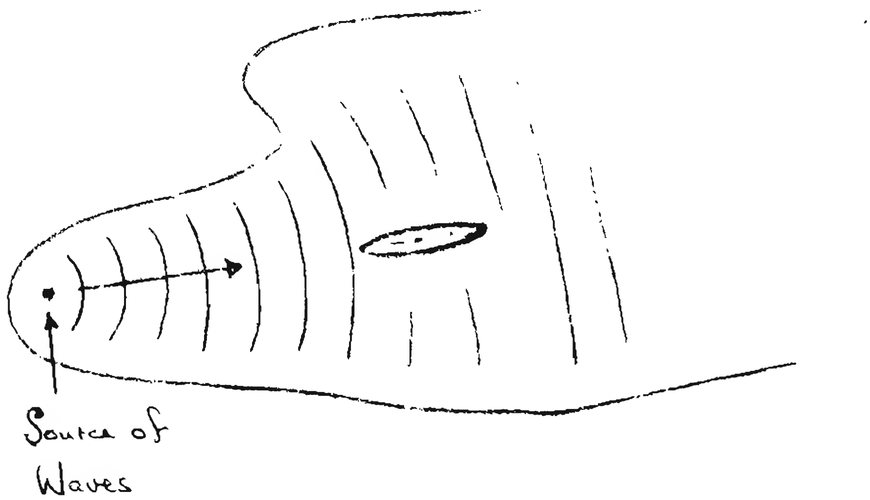
Do you have a clear picture in your mind of what a wave is, and just how it behaves? Let's try testing that picture. Have you ever stood on the sea shore and watched the waves rolling in? I'm sure that most of you have. Out at sea the waves appear to have a definite direction, and you might expect them to approach the shore at a wide variety of angles dependent on the inclination of the shore line to the waves. Does this actually happen in practice?



If you have ever watched a surf rider you will probably have gained the impression that he is carried in towards the shore by the motion of water underneath him. But is this what really happens? If the water moves forward so rapidly what happens to it once it reaches the shore?



Have you ever tried to use the motion of water in such waves to move floating objects from one point to another? If not it is most instructive to try it. Simply throw a piece of wood into the middle of a pond, and see if you can push it to the edge by generating water waves at one side of the pond. What happens?



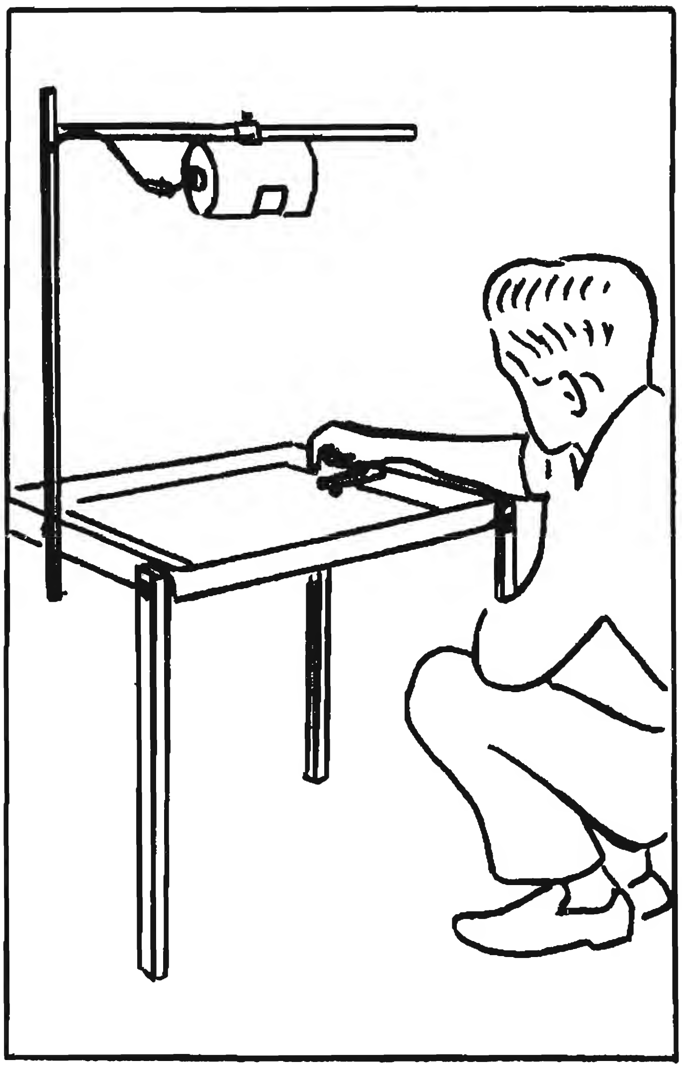
A study of waves will not only clarify such simple questions, but will also give us an amazing insight into phenomena which we might think are quite unrelated to waves, such as the colors created in colorless gasoline on asphalt road surfaces and the strange patterns created before our eyes when we look towards the sun on a bright day with our eyes almost closed.

With insight develops understanding, and the ability to control the phenomena that we observe, and it is such control which leads to new developments in science and technology. Let us then take a more careful look at waves in the laboratory, and see if we can understand them a little better.

3.10 NATURE OF WAVE MOTION

3.11 Waves and Pulses

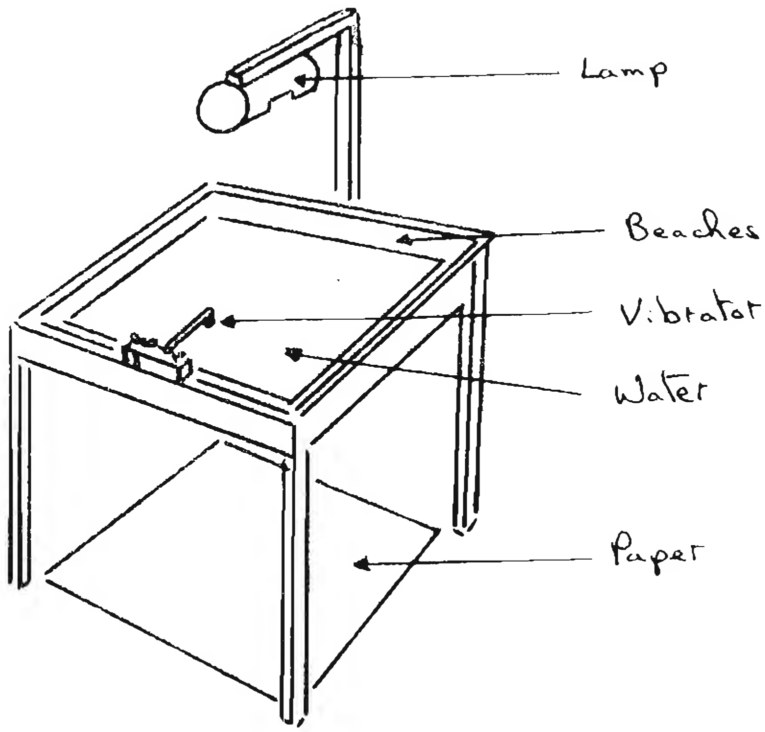
Apparatus Required



Qu	Apparatus	Item No.
1	Ripple Tank	3.10/01
1 sheet	Paper (58 x 58 cms)	
1	Cork (0.5 cm long, 1.0 cm diameter)	

Activities

(i) Set up the ripple tank provided, making sure it is clean before adding water to a uniform depth of around 1.0 cm. Adjust the tank legs accordingly. Switch on the lamp, but limit the period of lighting in order to prevent overheating of the lamp housing. Note the images created on the paper placed beneath the tank when the water surface is disturbed. If you tap the framework of the tank you will realize the importance of not touching it while performing an experiment.



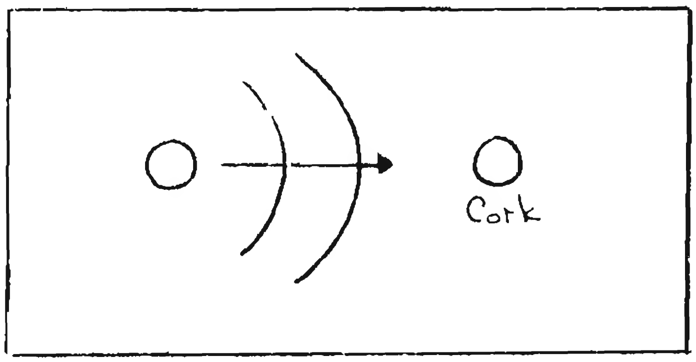
Adjust the vibrator so that it protrudes about 10 or 15 cms from the edge of the tank, and just touches the surface of the water. Tap the end of the vibrator, and see if you can produce a simple wave motion. Study the pattern on the water's surface and try to relate it to the pattern created on the paper below the tank. Does electrical lighting seem essential for studying such wave patterns?

In making observations it is often preferable to create a single disturbance rather than a continuous wave form. Using your finger try creating a limited disturbance with only one or two crests. (If you could create a single crest, or a single trough, on its own we would refer to it as a single pulse.) If we refer to the continuous line of a crest as a wavefront, is there any relation between the direction of motion of a disturbance and the wavefront created?

Out of interest take a pencil and hold it as steadily as possible in your hand so that one end is just in contact with the water's surface. Do you notice anything unusual?

(ii) Create a single disturbance at the center of the ripple tank. Do disturbances, and hence waves, move in one or more directions? From the shape of the disturbance created can you say anything about the speed at which the disturbance moves in different directions?

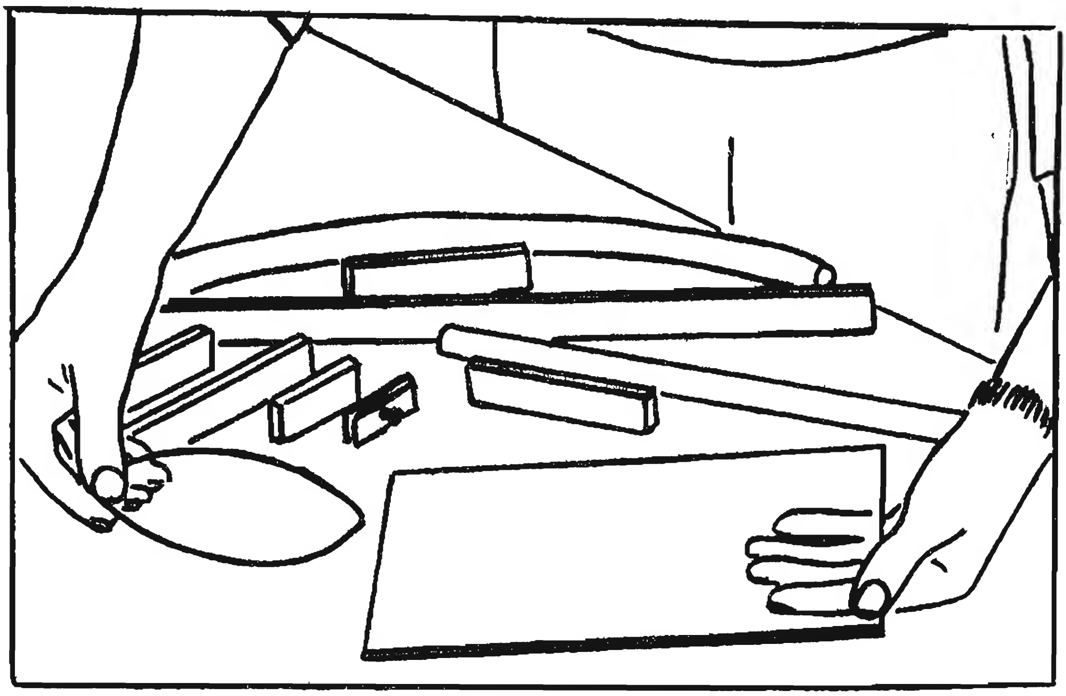
Take a cork, roughly 1 cm in diameter and about 1/2 cm in depth, and float it on the water surface. Create a single disturbance and see what effect this has on the cork. Is the cork carried forward by the disturbance? What is actually moving forward?



If the single source was made to vibrate continuously what would happen to the cork? With this in mind can you suggest what is being carried forward from the source to the cork by the waves?

3.12 Reflection and Refraction

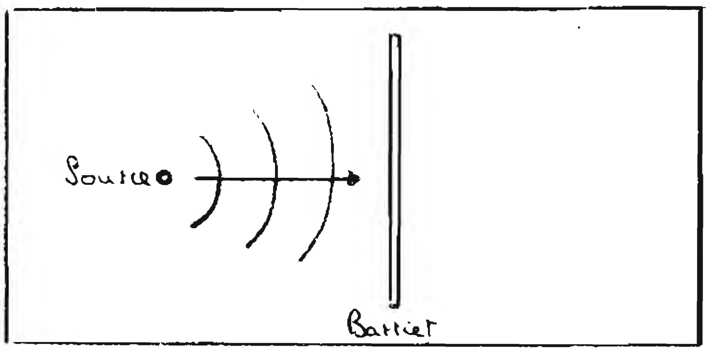
Apparatus Required



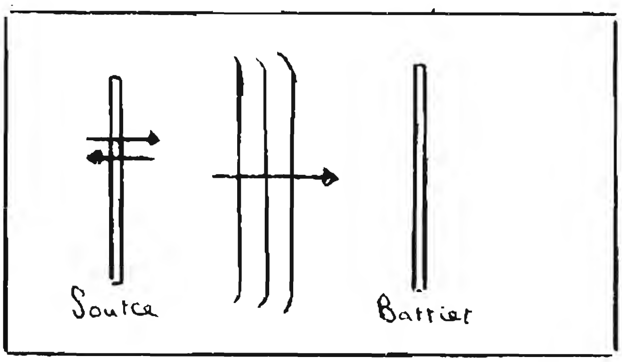
Qu	Apparatus	Item No.
1	Ripple Tank	3.10/01
1 kit	Ripple Tank Accessories	3.10/02
1	Magnet Wire (#24, 30 cms long)	

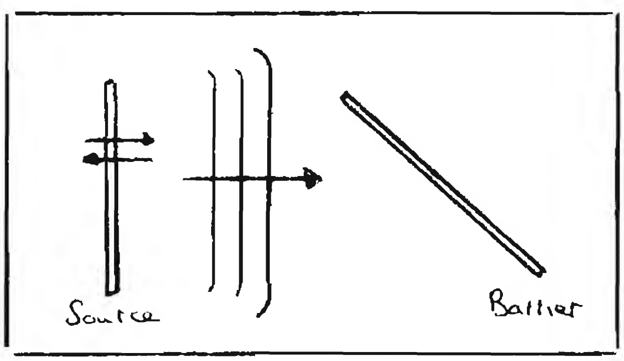
Activities

(i) Take a barrier and stand it in the tank some distance from the source so that the top surface stands clear above the water. What effect does the barrier have on a single disturbance, or for that matter a series of disturbances (a wave)? Study the shape of the wavefront after it bounces off the barrier. If you could not see the barrier, from where would you suggest this wavefront originated? Let us refer to this point of apparent origin as the imaginary source. You can check your deductions by generating single disturbances with your fingers from the two positions in question (the source and imaginary source) at one and the same time.



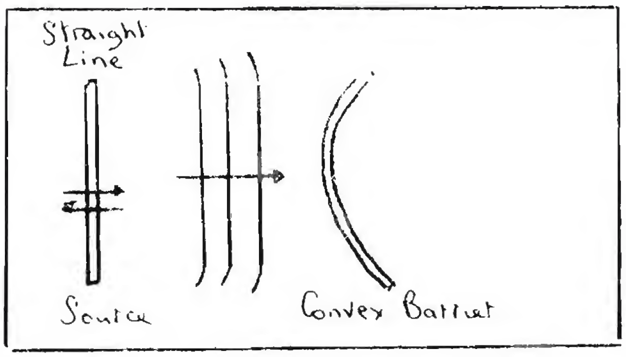
(ii) In studying the effect of barriers on waves it is particularly valuable to experiment with "line sources" as well as "point sources" so that the effect of the barrier on plane (straight) wavefront can also be observed. In this case it is suggested that you create a single disturbance with the "straight line source" (cylindrical rod) provided. Simply lay the rod horizontally in the water and then roll it sharply forward and back.

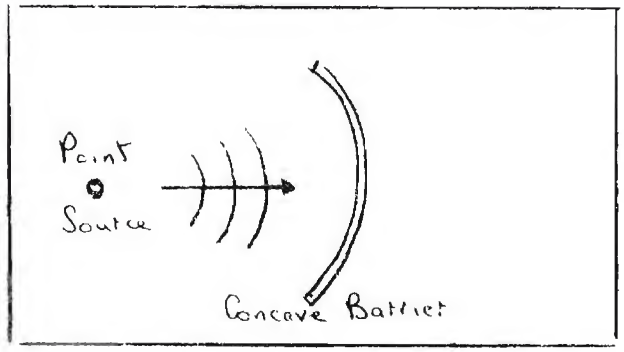




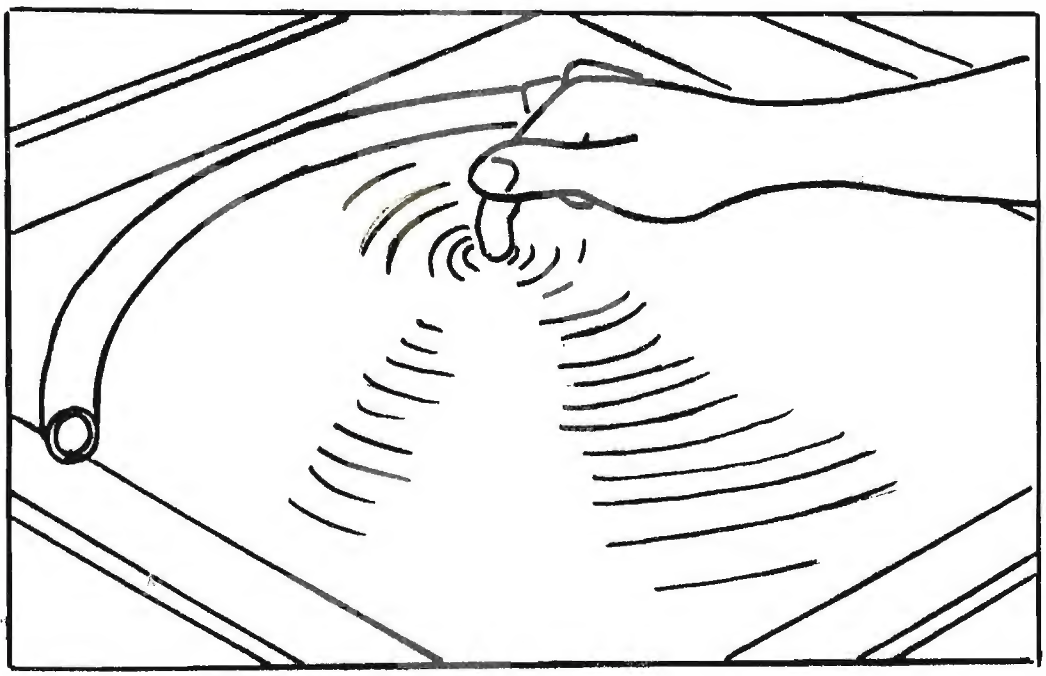
Try placing the barrier at varying angles to the wavefront created, and note the direction of the reflected wavefront. Having done this for two or three positions of the barrier try predicting the direction of the reflected wave for various barrier positions. Are the directions of motion of the incident and reflected wavefronts in any way related?

(iii) Replace the straight barrier by a curved one and see what happens when a plane wavefront strikes the concave side, and what happens when a plane wavefront strikes the convex side.

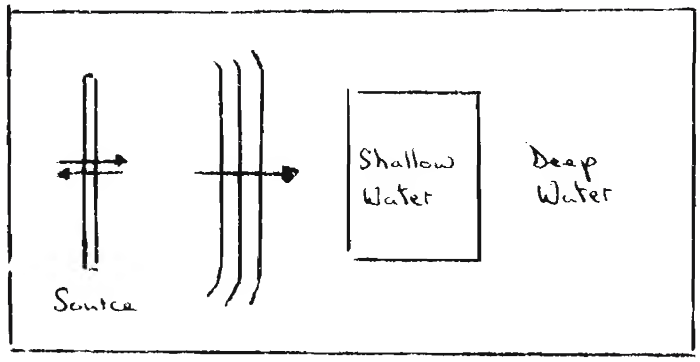




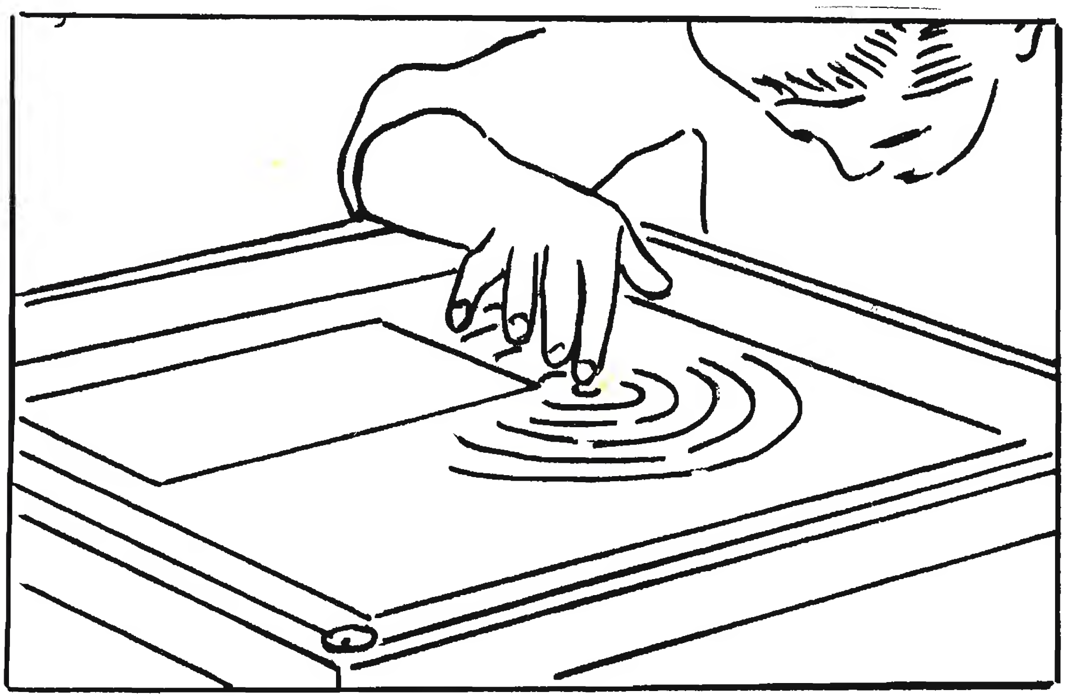
Now replace the straight line source by a point source (your finger). Using either the convex or concave side of the curved barrier can you under any particular circumstances convert an incident curved wavefront into a plane reflected wavefront? Make a series of sketches to illustrate the changes of wavefronts which you observe.



(iv) So far we have observed wavefronts moving forward over uniform depths of water. Let's now see what happens when the depth of water varies. Place the rectangular sheet of glass provided in the water with its long edge parallel to the straight line source, and adjust the depth of water until the thinnest possible layer covers the top of the glass plate uniformly.

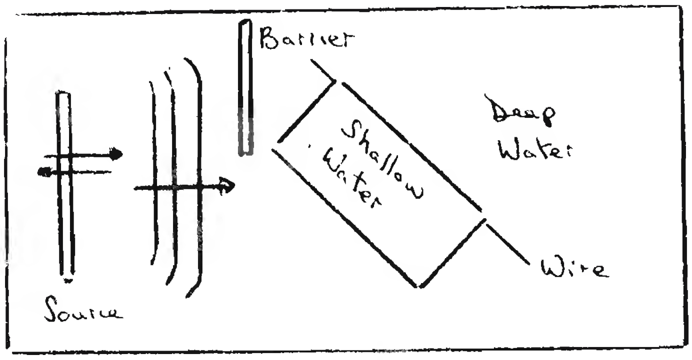


Generate a single plane wavefront and note the resultant motion. In this instance you might find observation simpler if you generate a series of successive disturbances, so long as you observe the resultant wave pattern directly and not through the water surface. Apart from drawing the motion of the resultant wavefront can you express the difference between the rates of motion in shallow and deep water? Is the speed of the wavefront over the glass plate affected by increasing the depth slightly?



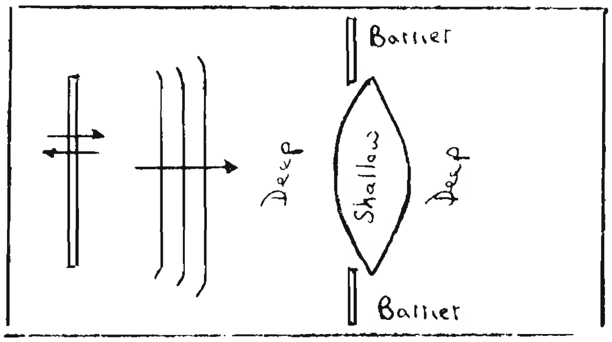
Similar observations may be made using a point source (a finger) to generate a circular wavefront at the edge of the glass plate, including the corner. Do you draw the same conslusions from these observations?

(v) Once again generate plane wavefronts and observe their behavior when they travel over the glass, when the front edge of the glass is placed at an angle to the wavefront. The observations can be simplified by using a barrier to eliminate some of the confusing edge effects that are normally created.



This last experiment has probably given you a clue as to why waves approaching land always have wavefronts parallel to the beach. It is in fact possible to make an imitation beach by lifting up one side of the glass plate. A piece of copper wire will raise the plate sufficiently to create a suitable beach. Once more generate plane wavefronts and observe how they turn onto the artificial beach. As before a barrier may be used to simplify the observations.

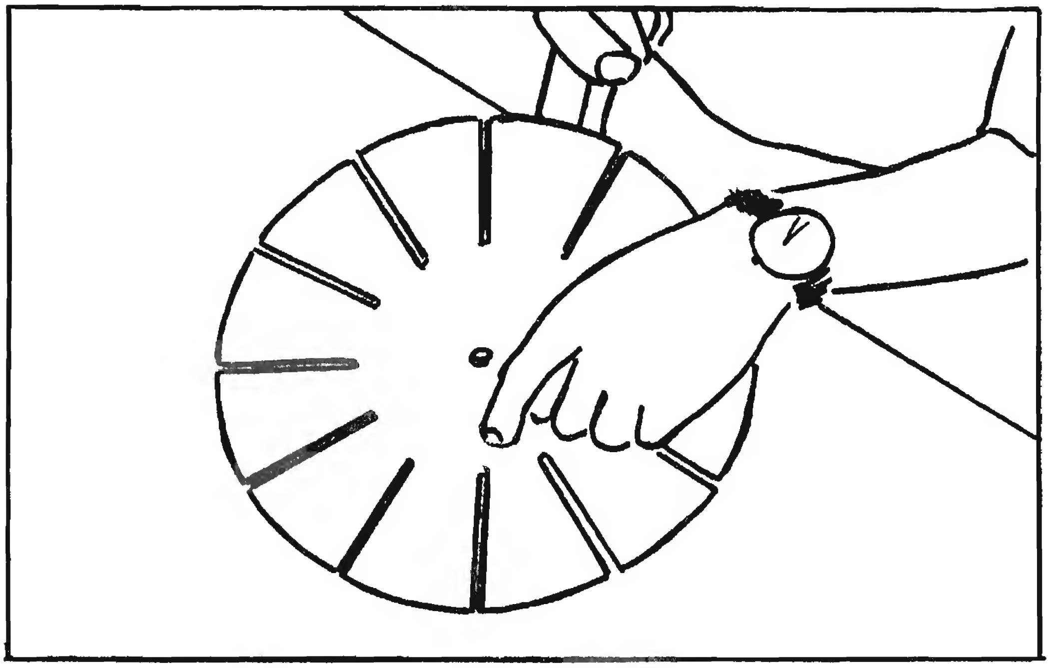
(vi) It is of interest to test out your newly found knowledge. A biconvex piece of glass is provided to create a shallow region of water in the same way as with the rectangular glass plate. However, before placing this in the water try to theorize as to what you would imagine might happen to a plane wave approaching the shallow area. Summarize your hypothesis in the form of a sketch illustrating the wavefronts that might occur. Then, and only then, place the biconvex glass plate in the



tank and see what hapens in reality. Draw a sketch illustrating the actual behavior of the wavefronts and compare this with your original hypothesis.

3.13 Velocity, Frequency and Wavelength

Apparatus Required



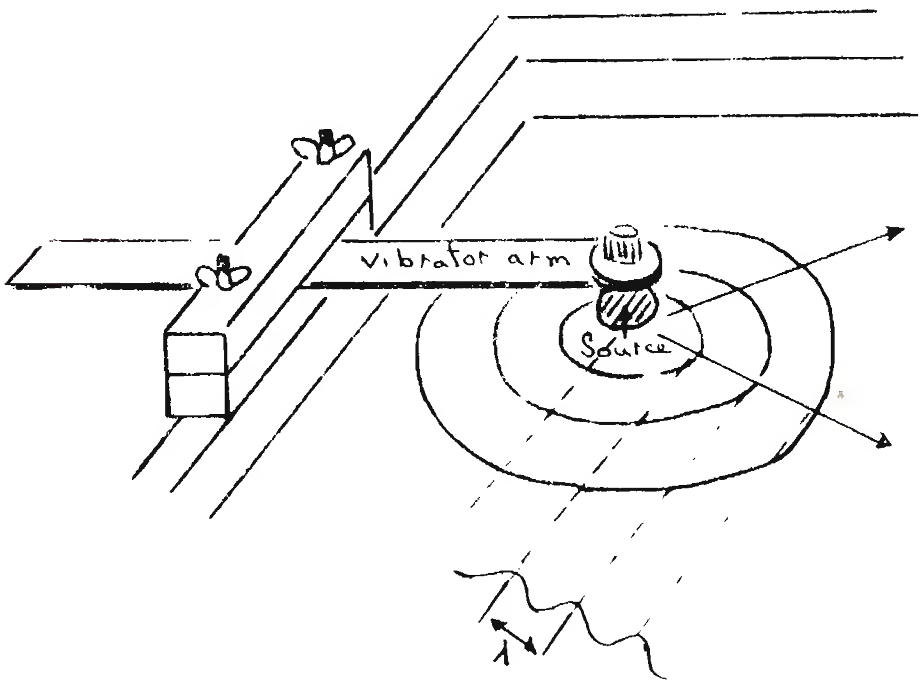
Qu	Apparatus	Item No.
1	Ripple Tank	3.10/01
1 kit	Ripple Tank Accessories	3.10/02
1	Stroboscope	3.10/03

Activities

(i) We already know quite a lot about the behavior of wavefronts from single disturbances, and we might well theorize that the behavior of wavefronts from a continuous series of disturbances (in other words a wave motion) will follow a similar pattern, and this can readily be tested out.

Let's test out our ability to develop theories (hypotheses). We have already seen that the velocity of a wavefront depends on the depth of water over which it moves, but that the velocity remains constant in a fixed depth of water. Wavefronts can be created in rapid succession one after the other or somewhat spaced apart. Do you think that the velocity of the wavefronts will be affected by the rate at which they are created? Think carefully about this, and then test out your ideas.

Fill the tank with water to a uniform depth of about 1 cm. Fix the ripple tank vibrator in the clamp on the tank frame so that the source itself is about 15 cms from the clamp. Adjust the position of the source so that it just dips into the water. Tap the end of the vibrator, and note what type of wave motion is created. Is there anything of interest that you can report



about the separation of consecutive wavefronts while the frequency 'f' of the vibrating source remains steady. For convenience we shall refer to the

separation between such consecutive wavefronts as the wavelength 'λ' of the wave motion. Now shorten the length of the vibrator to about 10 cms, and repeat your observations. What happens to the frequency 'f' of the vibrating source, the wavelength 'λ' of the motion created, and the velocity 'v' of the wavefronts?

(ii) You might not be too sure about what happens to the velocity, and it is worthwhile performing a more careful experiment. Clamp two vibrators side by side, about 5 cms apart, so that each protrudes about 10 cms from the clamp. The two sources can be made to vibrate with very different frequencies by fixing a 50 gm mass to one of the vibrators. Tap the end of each vibrator separately and note the frequency of each vibration and the wavelength of each wave motion produced. Then vibrate both simultaneously to determine whether the velocity of one motion is greater than that of the other. What do you conclude?

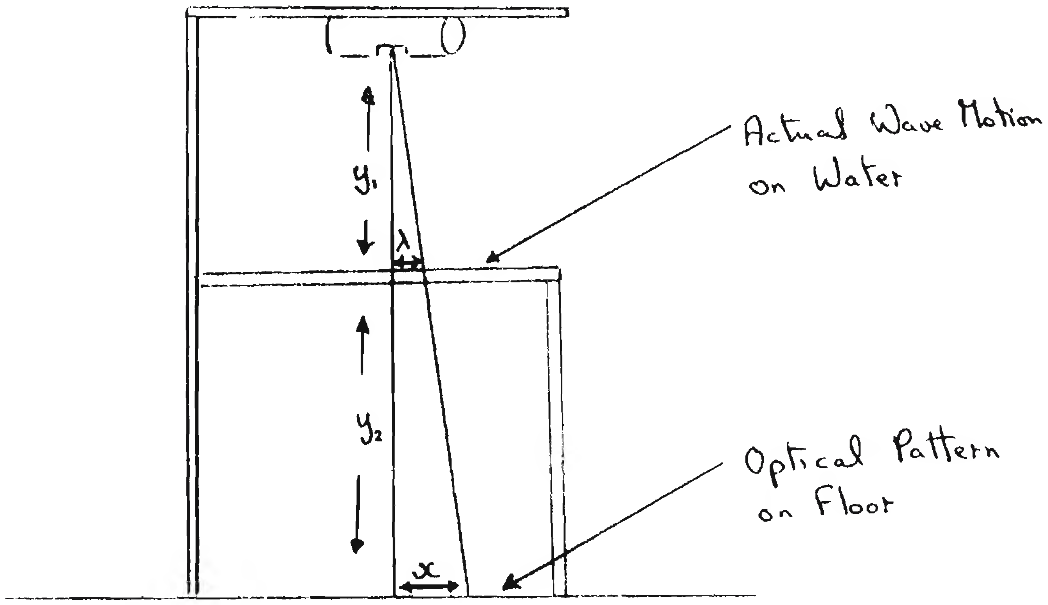
(iii) Set up a high frequency motion with the ripple tank vibrator (7 cms long). Ask your partner to tap the vibrator at regular intervals, so that a continuous wave motion is created. Observe the wave pattern created beneath the ripple tank through a hand held stroboscope. If you vary the speed of rotation of the stroboscope you should be able to make the observed pattern stand still. This indicates that each time you catch a glimpse of the pattern through a slit in the stroboscope that the wavefronts have moved forward by exactly one wavelength, thus appearing to be stationary.

Place a paper scale (marked off in centimeters) on the floor beneath the tank, so that looking through the stroboscope you can determine the wavelength of the pattern on the floor. You will find a paper scale easier to see than a meter ruler.

If you know the height 'y_2' of the waves in the tank above the floor, and the height 'y_1' of the lamp filament above the waves, then it is possible to determine the wavelength 'λ' of the actual waves from the wavelength 'x' of the pattern on the floor simply by substituting in the relation below:

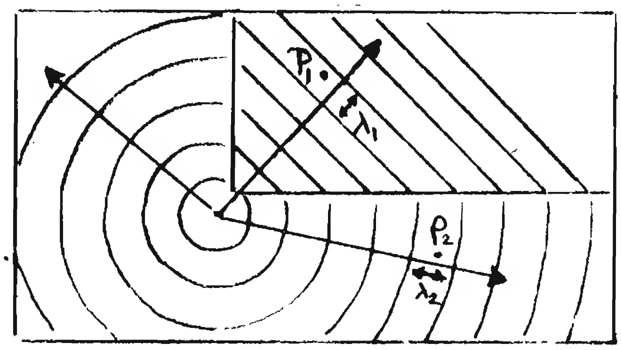
$$\frac{\lambda}{x} = \frac{y_1}{(y_1 + y_2)}$$

You should have no difficulty in seeing how this relation is derived if you study the diagram below and recall your findings in the earlier triangulation experiments. Determine the wavelength of the motion you have been observing.



Now set up a low frequency motion with the ripple tank vibrator, (7 cms long, but weighted with 50 gm mass) and repeat the above experiment. Compare the wavelengths of the two motions.

(iv) We have already seen that when waves move from a deep area of water to a shallow area that the velocity and wavelength of the motion is changed. The question we might now ask is whether the frequencies of the



two motions are still the same or not.

Let's hypothesize that the frequencies are identical. This would mean that the number of wavefronts passing the point P_1 in a fixed interval of time 't' would equal the number of wavefronts passing the point P_2. If such a motion is observed through a stroboscope a fixed interval of time 't' exists between the viewing of the motion through successive slits. If the frequencies of the two motions are the same it should follow that the same rate of rotation of the stroboscope will stop both wave motions simultaneously.

Now test out this hypothesis. Place the rectangular glass plate in the ripple tank so that the water just covers its surface. Get your partner to generate continuous vibrations (with the ripple tank vibrator) in the water at one corner of the glass plate. Rotate your stroboscope and attempt to stop either of the motions. Are the frequencies of the two motions the same?

3.20 INTERFERENCE AND DIFFRACTION

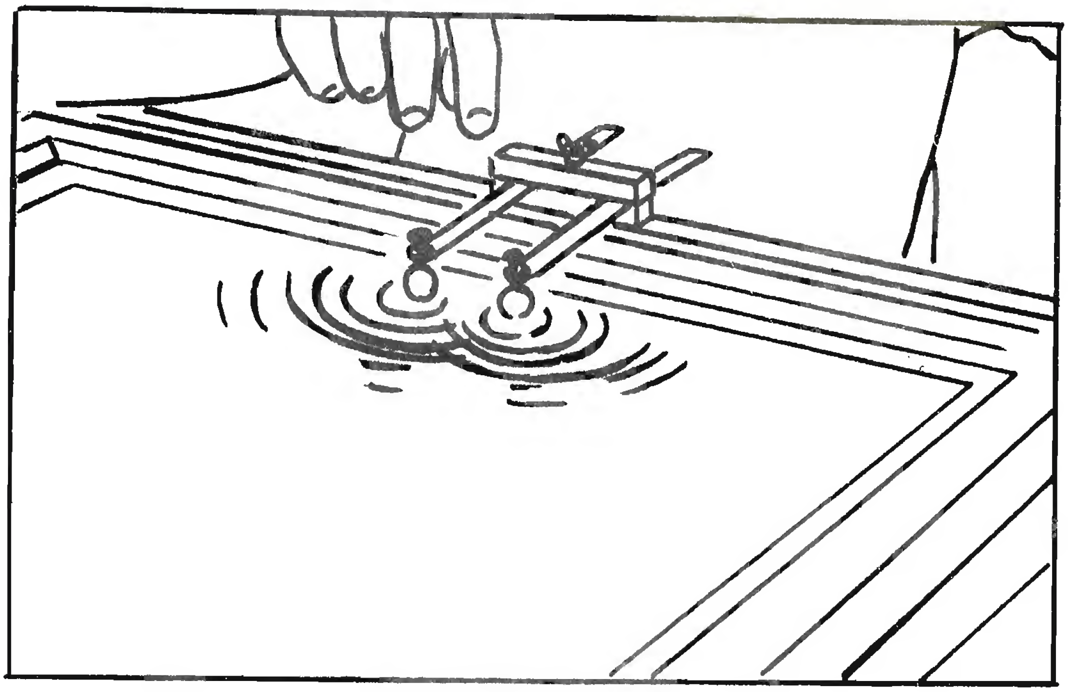
3.21 Interference and Diffraction

Apparatus Required

Qu	Apparatus	Item No.
1	Ripple Tank	3.10/01
1 kit	Ripple Tank Accessories	3.10/02

Activities

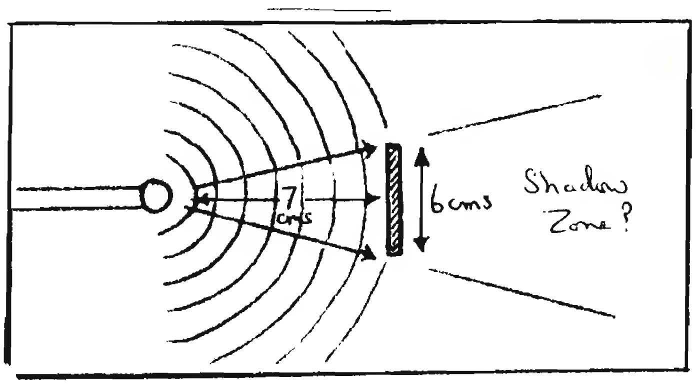
(i)



Clamp two vibrators side by side, about 5 cms apart, so that each protrudes about 10 cms from the clamp. Set the two sources vibrating simultaneously. Study the pattern created by the overlapping wavefronts. It might take a few seconds for you to recognize any pattern. Can you sketch roughly what you observe? You might repeat the process altering the separation of the sources to 7 cms and then to 3 cms. Does the same type of pattern emerge?

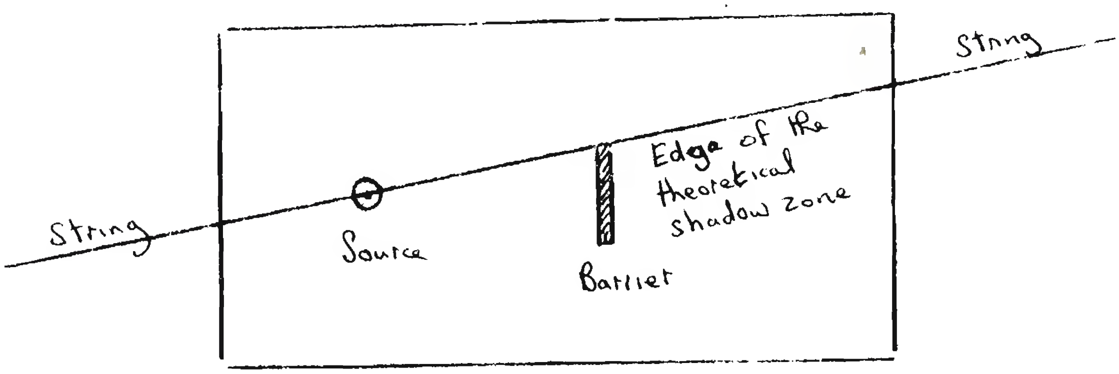
(ii) In some of your previous experiments when using barriers and rectangular glass plates you might already have noted some rather peculiar wavefront patterns. Could it be that the barriers didn't cut out the wavefronts quite as well as you expected, or that wavefronts appeared in unexpected places and forms? It is well worthwhile creating a simple enough setting to investigate such behavior more thoroughly.

Let's investigate whether obstacles are able to cut out parts of wavefronts efficiently. To do this adjust the length of the vibrator to about 7 cms so that it will produce fairly high frequency vibrations, and hence waves of fairly short wavelength. Place the short barrier (6 cms long) about 7 cms from the source. Set the source vibrating.



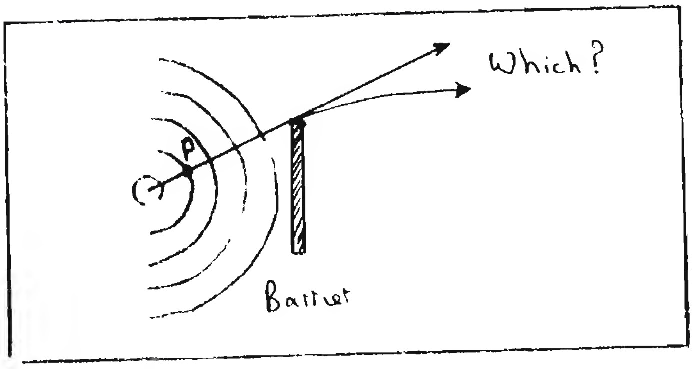
Is there anything which might be considered as a shadow zone created by the barrier? Sketch the appearance of the wavefronts produced beyond the barrier.

In order to obtain meaningful observations it is helpful to mark out a theoretical shadow zone on the paper beneath the tank. Two meter rulers can act as convenient markers. Equally well the location of the markers can be ascertained by holding a piece of string so that it just touches the center of the source and the edge of the barrier. The shadow of the string created on the paper beneath the tank clearly marks out the theoretical shadow zone. In your sketches you should indicate the form of the wavefronts in relation to the theoretical shadow zone.



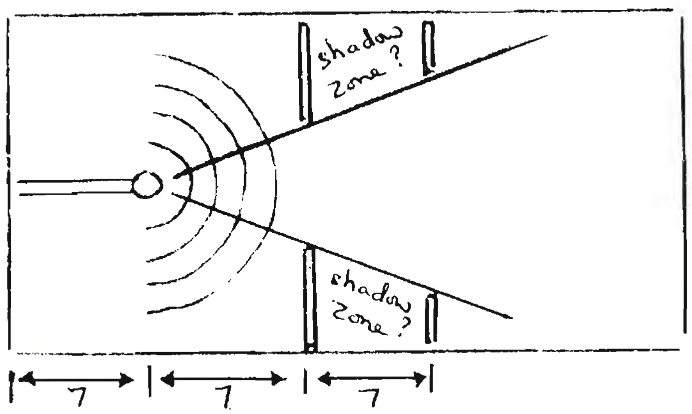
Repeat the experiment with a 50 gm mass attached to the end of the vibrator. This will provide you with a low frequency source, and hence a wave motion with a long frequency. Are the waves related to the shadow zone in the same way as with the high frequency source.

(iii) It is proposed that you repeat the above activity for wave motions with long and short wavelengths with a barrier 2.5 cms long, and another 1.0 cm long. The main point to be determined on each occasion is whether a given point (P) on a wavefront moves forward past the barrier along a straight line or not. Do your results show that a barrier always obstructs a wave motion?



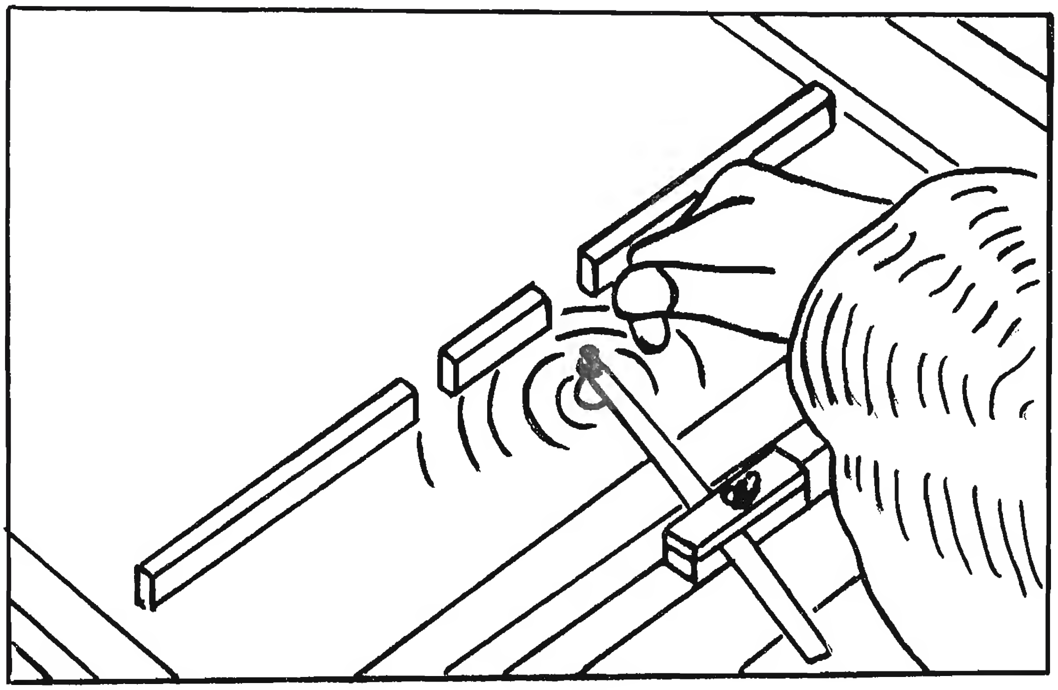
(iv) You should now be able to predict the behavior of waves as they pass through apertures created by two barriers. In making observations it is useful to use two sets of barriers, one set to create the initial aperture, and the second set (parallel to, but about 7 cms beyond, the first set) to mark out the edges of the theoretical shadow zone.

Set your first set of barriers up to create an aperture 7 cms wide. Generate low frequency waves, and note the behavior as they pass through the aperture. Next generate high frequency waves, and observe their passage through the aperture. Under what conditions do you find a fairly clear shadow zone similar to the theoretical one drawn?



(v) Repeat the foregoing activity with an aperture only 1 cm across. What patterns do you observe with the low and high frequency wave motions?

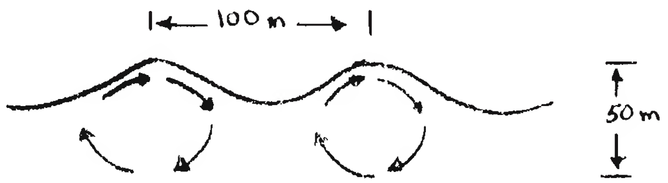
Now create two apertures 1 cm wide and 6 cms apart. Generate a continuous low frequency wave motion, and observe the patterns beyond the apertures. Have you seen a similar pattern before? Can you explain how it is created?



3.30 IN PERSPECTIVE

All your observations to date have been made on very small waves in a ripple tank. In concluding it is therefore worthwhile putting your observations into perspective.

In the ripple tank the waves you observed would have wavelengths varying from 1 to 3 cms, but in an ocean "swell" the wavelength may be as much as 100 meters, and the surface disturbance reaches down as far as 50 meters.



Approaching a shore line the wave disturbance may actually touch the sea floor at a depth of 50 meters. From a distance you can often follow the ensuing behavior. The wave crests move forward more slowly, once the bottom is touched, and rise higher and higher out of the water until they can no longer support themselves, finally crashing down in a spray of foam.

Such waves are initially generated by winds and storms. The turbulent waves created give way to smoother wave forms called "swells" which can carry a storm's energy half way round the world, much further than might be expected from observations with the ripple tank. The amount of energy which can be released by such waves when they strike a shore line is staggering. Records exist to show that in a gale on the Oregon coast line a 65 kgm rock was hurled through the air to knock a gaping 7 meter hole in the roof of a lighthouse. The lighthouse was more than 30 meters above the sea. During a gale in Scotland a block of concrete weighing 2,600 tons was swept from the breakwater. Such is the energy released that it has been calculated that a wave 1 meter high collapsing on 1 kilometer of beach would generate well over 15,000 horse power in little over a second.

As yet no one has attempted to harness this power, but engineers are beginning to draw power from the motions of the sea in a somewhat different form. In 1967 France completed the first ever Tidal Power Station by constructing a dam across the mouth of the river Rance in Brittany, where the two high tides

per day may be as much as 14 meters above the level of the low tides. The station now produces about 540 million kilowatt hours of power per year, which is roughly equivalent to the power that would be produced by an 83,000 horse power engine operating 24 hours a day for 365 days in the year.

4. OPTICS

A study of wave phenomena leads very naturally into investigations into the nature of the transmission of sound (acoustics), light (optics), heat (infrared radiations), as well as rays of all descriptions (gamma rays, x-rays, ultra violet rays, visible rays, and infra red rays). These phenomena may be studied initially from the same point of view in an attempt to determine the method by which transmission occurs, and it is suggested that a study of optical phenomena will give us some insight into the techniques used.

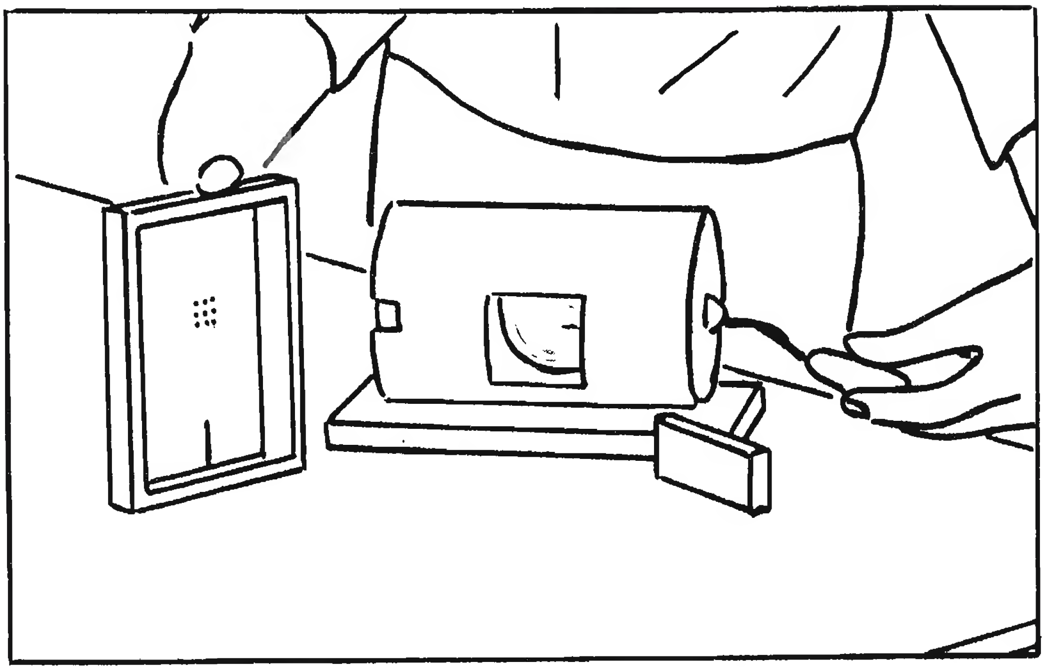
We choose optics in particular for in the seventeenth century considerable controversy arose between two famous scientists regarding the nature of light transmission. On the one hand the British scientist Sir Isaac Newton suggested that light consisted of particles which were emitted from light sources such as the sun, while the Dutch scientist Christian Huyghens suggested that light was transmitted as a wave motion.

It is our intention here to attempt to create such phenomena as reflection, refraction, diffraction and interference in light, on the logic that if light does behave as a wave motion it is not unreasonable to anticipate that such phenomena might be visible to the eye. We will note carefully whether such optical phenomena can be created, and if so under what conditions. We will then try to determine how the specified conditions affect the two theories proposed. Finally, we will collect all our observations together, and attempt to determine which, if either, "light model" fits our observations best, accepting that it may not be an ideal model, but simply the better of the two models offered.

4.10 PROPAGATION, REFLECTION, REFRACTION

4.11 Propagation

Apparatus Required

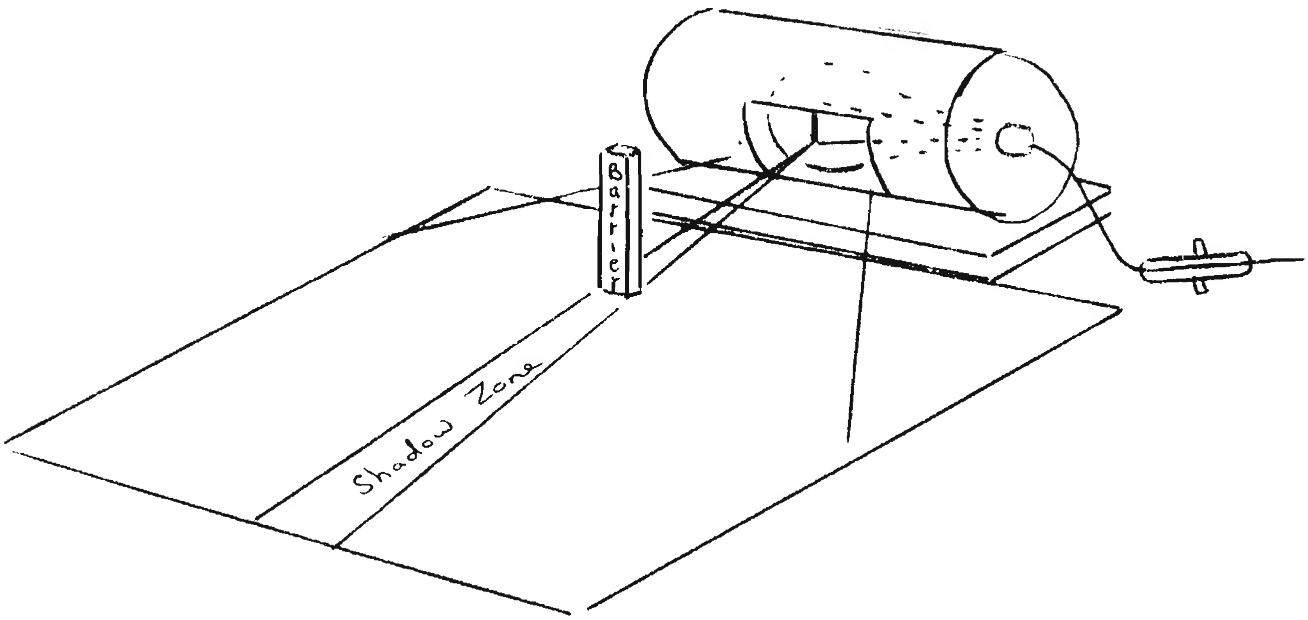


Qu.	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Wooden Barrier (8 x 3 x 0.8 cms)	
1	Slit/Aperture Combination	4.10/02
1 large	Sheet of White Paper (4 bond sheets joined together to cover an area approximately 100 x 75 cms)	

Activities

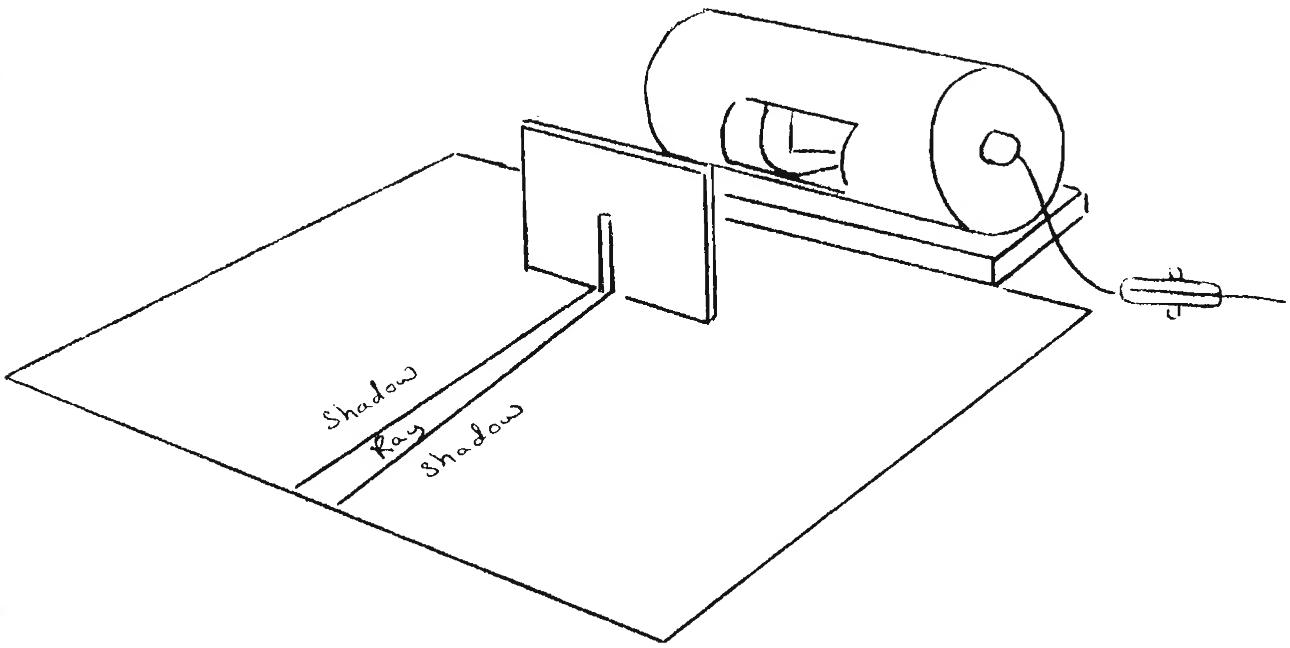
(i) The first question to be answered is how is light transmitted from a source. Does it travel out from the source in all directions or just in one direction? The light source provided is surrounded by a lamp house with only one opening for the emission of light, but if the housing was removed would light travel out in all directions or not?

Turn the light source so that the straight line filament is vertical, and the light from the aperture spreads visibly across a sheet of paper placed on the table in front of it. Place a barrier in the path of the light to see if there is such a thing as a theoretical shadow zone created. Does the light bend noticeably into the theoretical shadow zone?



Remove the barrier from in front of the light source. Does the light move forward immediately into the shadow zone? If the barrier is knocked out of the way instantaneously do you see the light move forward or is the motion too fast to follow?

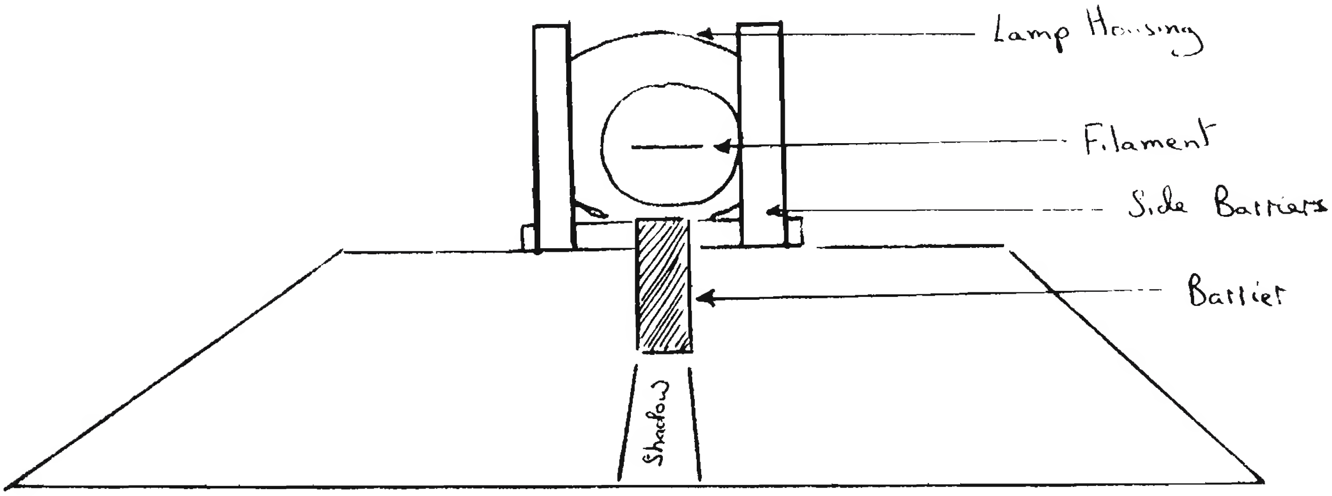
(ii) Replace the obstacle by a slit. Is the shadow zone what you would have predicted? Place the slit in several different positions in the path of the emitted light. We might refer to the light transmitted through the slit as a narrow beam, or ray, of light. For each position of the slit draw lines representing the direction travelled by the midpoint of each ray. Trace these lines backwards until they meet. What appears to be the point of origin of each ray?



Place the slit very close to the light source. Observe the shape of the ray emerging from the slit. Now move the slit much further away from the source. Does the shape of the ray alter?

(iii) Take the lid of the lamp house, and point the source so that light falls on the paper from the end of the housing. Place two barriers either side of the front of the housing to eliminate confusing reflections, and one barrier in the light path. Study the edges of the shadow created by the single barrier.

Now turn the lamp through 90 degrees so that its filament is in a horizontal plane. Study the edges of the shadow beyond the single barrier

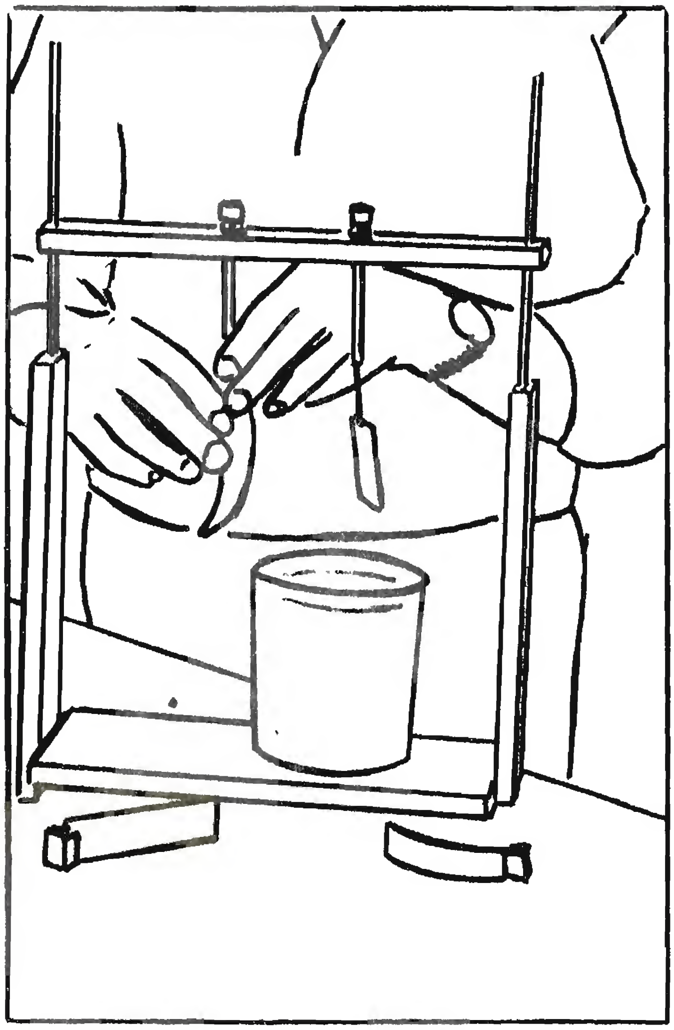


once more. Are they as distinct as before? Can you explain what you observe?

(iv) Summarize your observations with regard to the Corpuscular Theory and Wave Theory. If light was an emission of particles from the filament of the lamp you would expect the particles to move outwards in all directions from the filament following straight lines. If light was emitted from the filament as a wave motion it would spread out in all directions showing a tendency to bend round obstacles. Do your observations so far accept both theories as possible? If light was transmitted as a wave motion would you stipulate any required condition concerning its frequency, compared with the frequencies of waves observed in water?

4.12 Reflection

Apparatus Required

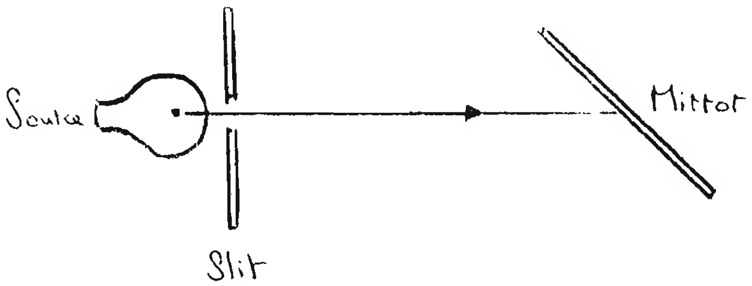


Qu.	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Slit/Aperture Combination	4.10/02
1	Plane Mirror with Holder	4.10/03
1	Curved Mirror with Holder	4.10/03
1	Optical Board with Optical Pins (2)	4.10/04
1	Wooden Barrier (8 x 3 x 0.8 cms)	
1	Protractor	
1 sheet	Plain Paper (100 x 75 cms)	

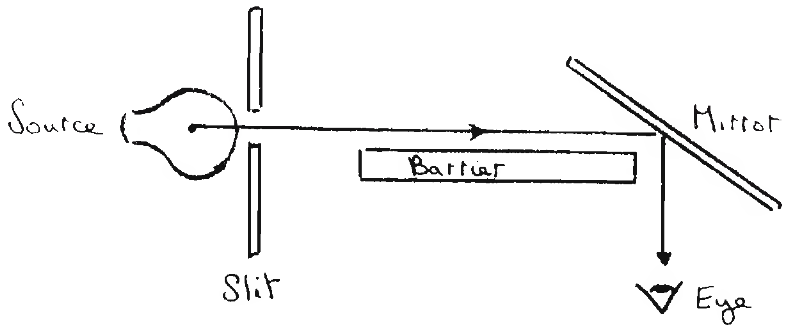
Activities

"Reflections" in mirrors, glass windows and water must already be a familiar everyday occurrence. For the present it is proposed that you refer to such familiar phenomena as images, for we have no reason, to assume that they are in any way connected with the reflection of waves (or rays) as seen in the ripple tank. We will certainly investigate the possibility of a relationship between such images and reflection of incident light, but we must be careful not to make any wild assumptions.

(i) A polished metal plate is provided to act as a mirror. Place this in the path of a light ray from the light source and record the position of the incident and reflected rays on the paper. Repeat this with the mirror inclined at varying angles to the incident ray. Can you predict the direction of any given reflected ray before you actually switch on the lamp? Is there any relationship between the position of the mirror and the directions of the incident and reflected rays?

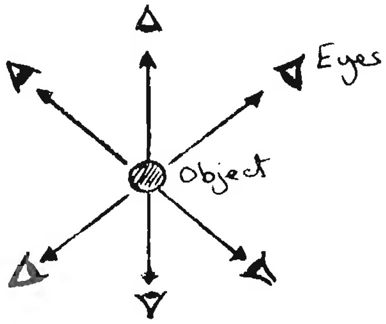


(ii) Adjust the position of the mirror so that you can place your eye close to the table top in the path of the reflected ray. It is now proposed that you concentrate on the image of the slit that can be seen in the mirror, and with this in mind it is useful to hide the incident ray behind a suitably located barrier so that only the image and reflected ray are visible. Look into the mirror. How would you describe the location of the image? Does it appear to be related in any way to the reflected ray?

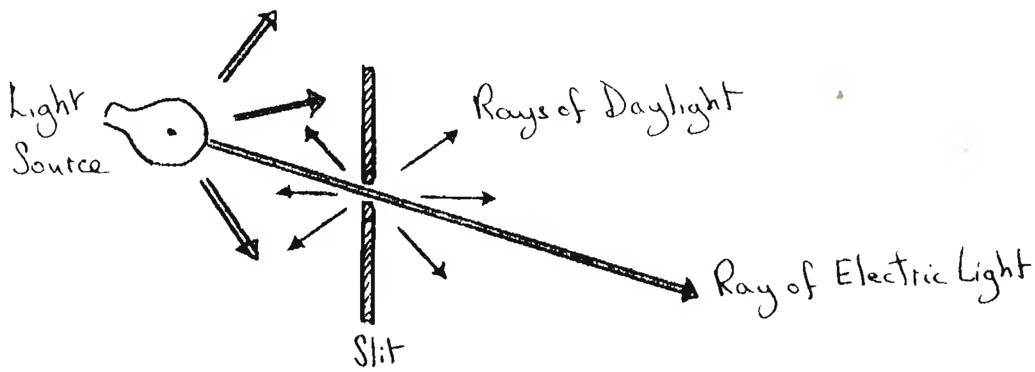


If you switch off the electric lamp what happens to the image in the mirror? Does the image disappear at the same time that the incident and reflected rays disappear? Is it possible that rays of light still pass through the slit to the mirror?

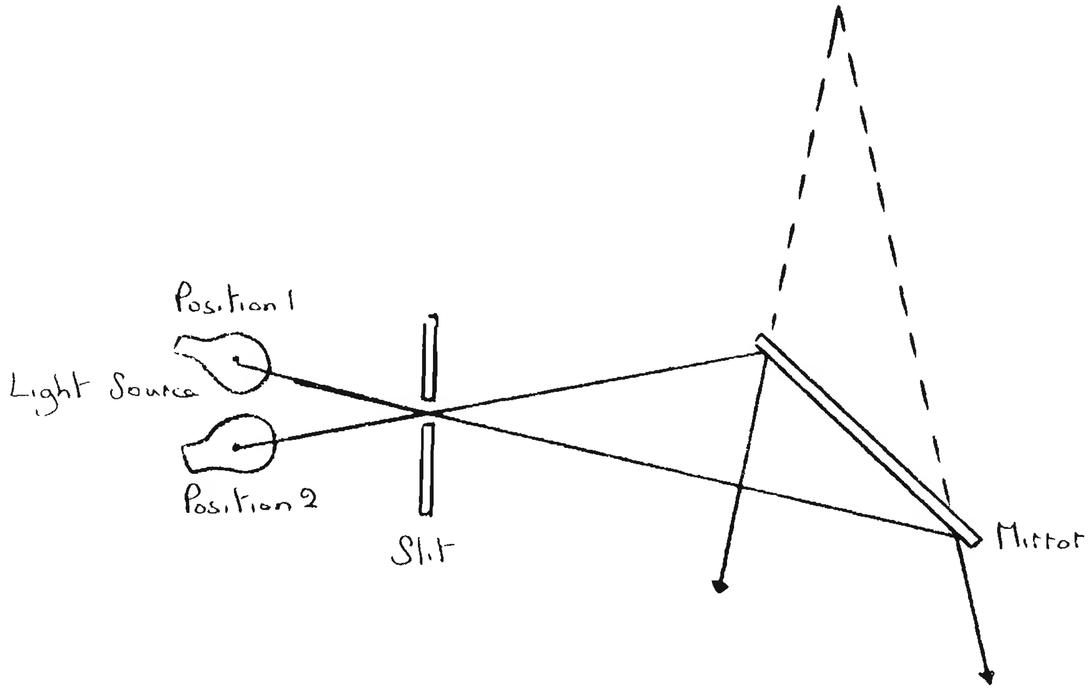
(iii) Let's try to build up a theory to explain what we have just seen. If an obstacle is placed in the middle of a table in a dark room it is invisible. But if daylight enters it can be seen clearly by people all around the table. It is suggested that the object must reflect light (daylight) in all directions, otherwise it would not be visible to all concerned. On the same basis it is theorized that light (daylight) must be reflected in all directions from the slit otherwise this would also be invisible.



When the light source shines on the slit it simply emphasizes the direction of one of the many daylight ray paths, the electric light being brighter than the daylight in the vicinity of the slit. By shifting the position of the electric light it should be possible to trace with an electric ray of light the direction of any possible ray of daylight.

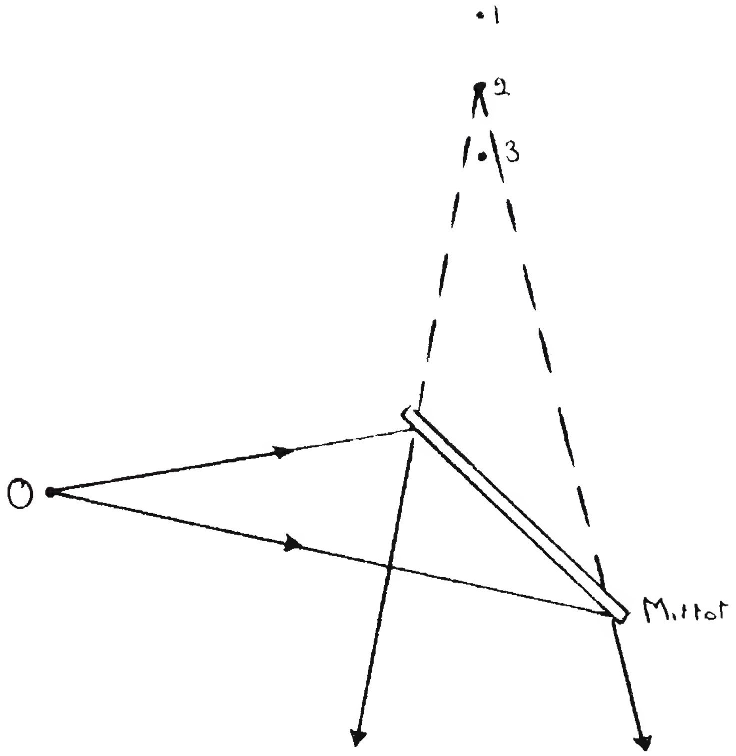


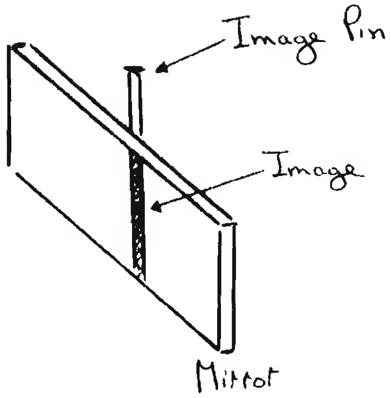
Let's test out our theory, and see what happens. Place the mirror at a suitable angle, and record the path of an electric light ray as it strikes the surface and is reflected. Keeping the slit and mirror positions fixed move the electric lamp sideways and repeat the recordings. This might be repeated for a third and fourth postion of the electric lamp. Extend the reflected rays back behind the mirror in your drawing



to see where they intersect. Do all the rays intersect at the same imaginary point or at different points? Try moving the lamp while you view the image in the mirror. Does each position of the electric lamp create a new position of the slit's image? Do you now feel that by the use of ray drawings, instead of actual rays, you could determine the position in which you would expect to find an image of an object(in this case the slit)?

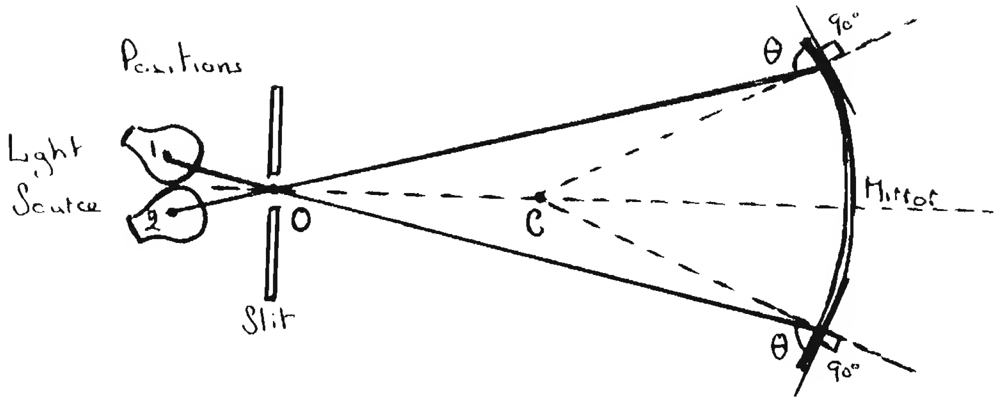
(iv) It is interesting to look at your last experiment from a slightly different point of view. Place the paper, on which you have already drawn the various light paths, on top of an optical board so that large pins can be stuck in the surface. Replace the slit by a vertical pin which you can refer to as the object pin (position 0), and place the second pin (image pin) behind the mirror (position 2) where you would expect to find an image of the object pin. (Use a white sleeved pin as the object pin.)





Now look into the mirror, and view the image and the image pin simultaneously. Move your head horizontally from side to side. Does there appear to be any relation between the movement of the image pin and the image? Repeat the same observations with all aspects of the experiment the same, but with the image pin further away from the mirror (position 1), and finally with it closer to the mirror (position 3). You should be able to use this technique of "parallax" to determine the position of any image in a mirror.

(v) Place the light source and slit in such a position that a ray of light falls on the curved surface of a concave mirror. Trace the direction of the incident and reflected ray on the sheet of paper placed on the table top. Repeat the experiment for two more positions of the light source. Extend the reflected rays back behind the mirror, and locate the position of the image of the slit. Do you detect any rule which the rays appear to follow when they are reflected?



C = Center of circle of which mirror is an arc

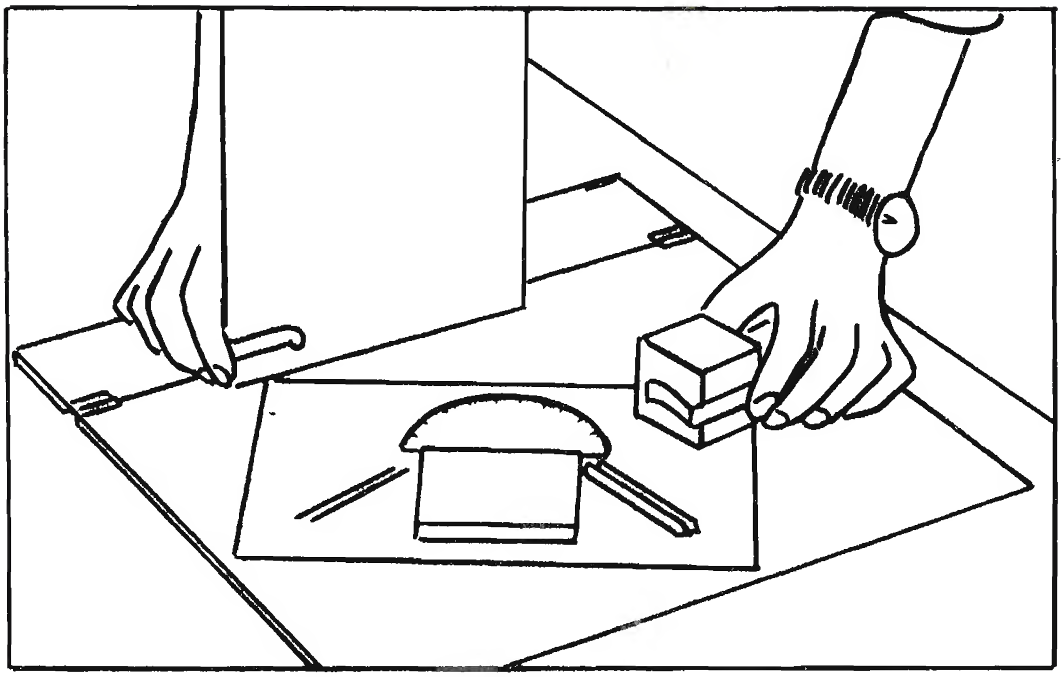
θ = Angle between the incident ray and tangent to mirror, at the point where the ray meets the mirror

Now replace the slit by placing an object pin in the exact same position (O). Keep the mirror in the same position, and stick an image pin in the paper where you have indicated the location of the image of the object. (It is preferable that you use a pin with a white sleeve as the object pin). Check by "parallax" whether the image pin and the image in the mirror are located in one and the same place. Keeping the object and mirror in the same position, move the image pin closer to, or further away from, the mirror. Check the behavior of the image and image pin by "parallax" in the new positions.

(vi) Summarize your observations concerning reflection, and see whether the two rival light theories still offer good explanations of what you have observed. In particular can both theories adequately explain why light is reflected at mirror surfaces in such a way that the angle between the reflected ray and the mirror equals the angle between the incident ray and the mirror? Did you see similar patterns of behavior when studying reflection with the ripple tank?

4.13 Refraction

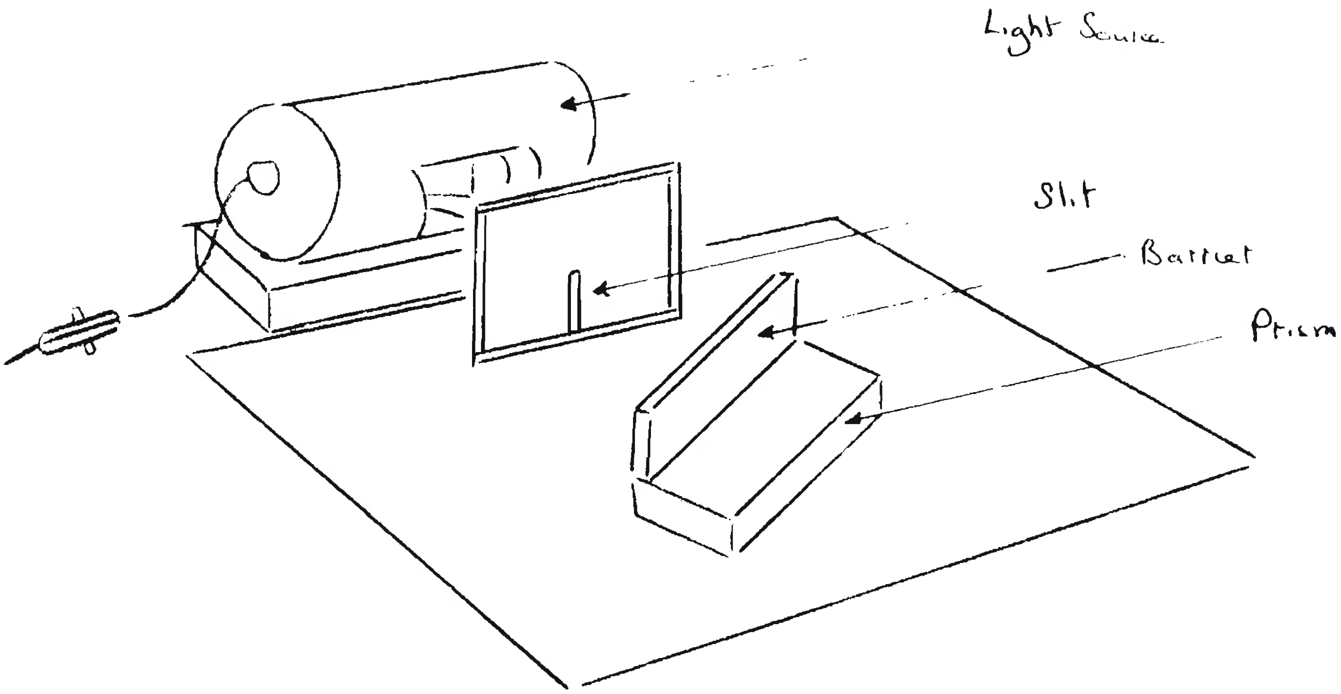
Apparatus Required



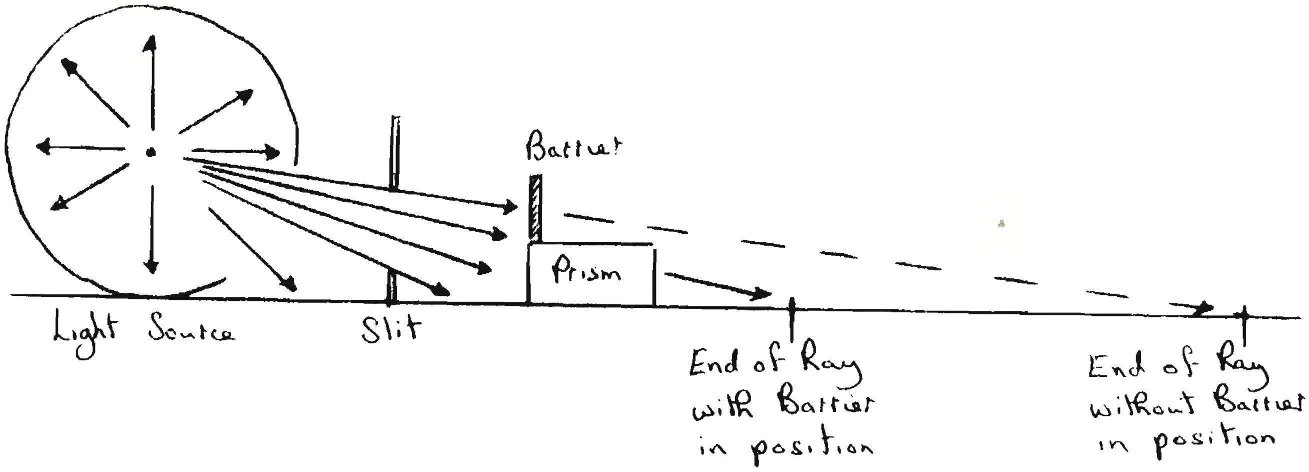
Qu	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Slit/Aperture Combination	4.10/02
1	Rectangular Prism	4.10/05
1	Refraction Model Apparatus	4.10/06
1	Wooden Barrier (8 x 3 x 0.8 cms)	
1	Protractor	
1 sheet	Plain Paper (100 x 75 cms)	

Activities

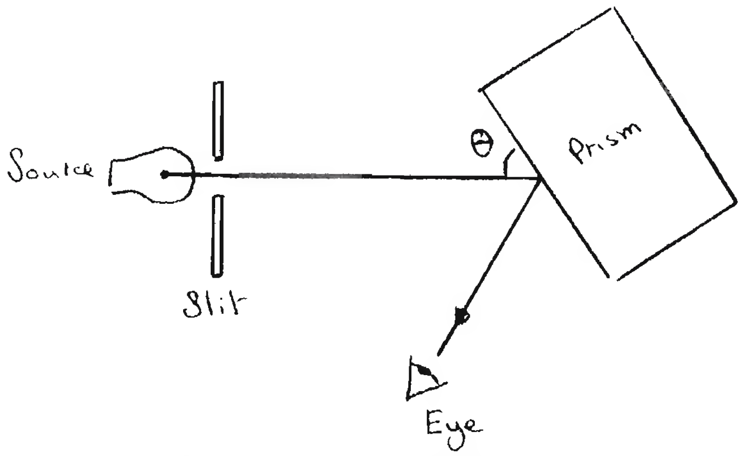
(i)



Set up light rays across your paper in the usual way with a light source and slit. Place the rectangular prism in the path of light, and sit a barrier on the top of the prism, at its front edge, so that light from the source is only able to enter the prism through the front side, and not through the top surface.

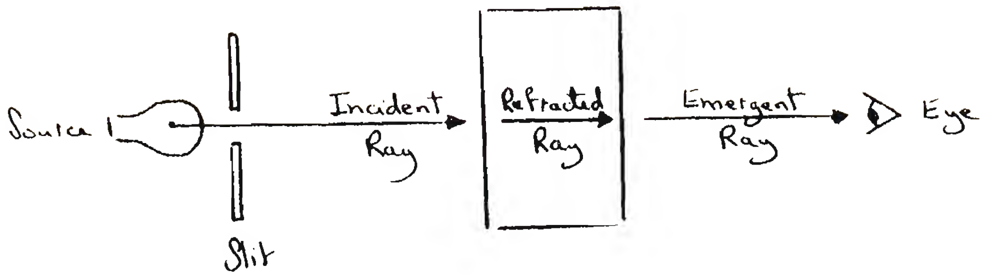


Viewing the apparatus from above concentrate your attention on what happens to a ray striking the front surface of the prism, first with the angle (θ) between the surface and the ray about 90°, and then gradually decreasing until the ray and the surface are almost parallel to one another. Is the ray reflected at the front surface? If so, is the intensity of the reflected light equally bright, regardless of the inclination of the front surface of the prism to the incident ray?

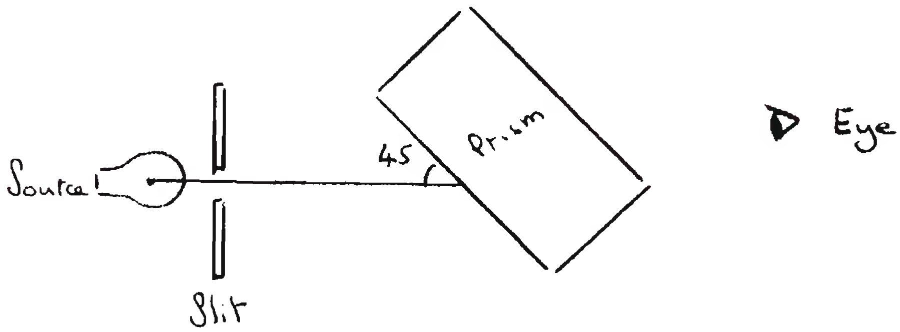


Finally, look into the front surface of the prism. Can you see an image of the slit? Can you vary the brightness of this image by simply varying the angle at which the incident ray strikes the front surface of the prism? Is there any relationship between the brightness of the image and that of the reflected ray?

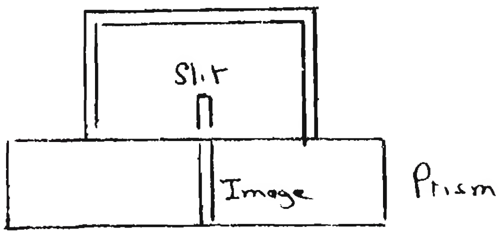
(ii) Set up the apparatus exactly as for the last experiment, but this time observe not only the light reflected by the prism, but also that transmitted through it when the angle (θ) between the incident ray and the surface of the prism is fixed at four different values: 90°, 80°, 45° and 10°. For each position of the prism draw a diagram to record your results indicating the brightness of each ray as strong (s), medium (m) or weak (w). In referring to your diagram you will find it useful to refer to the ray passing through the prism as a refracted ray (since under certain circumstances it is refracted or bent) and to the ray emerging from the prism as the emergent ray.



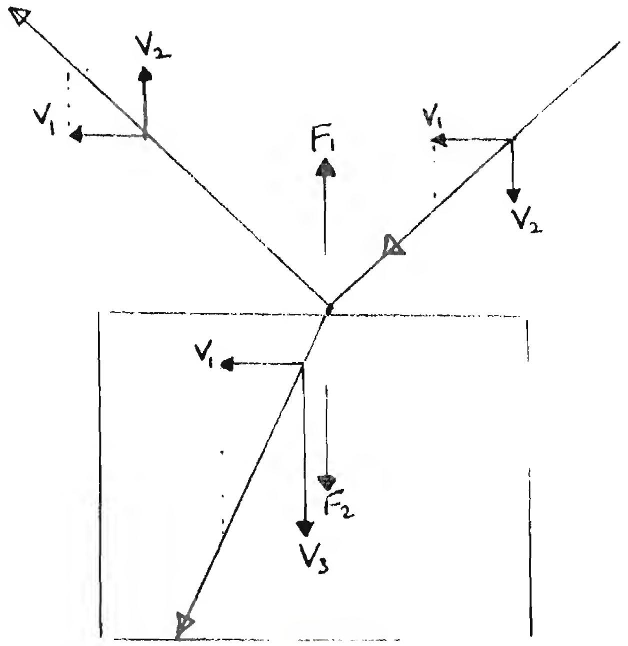
Now place the prism at an angle of 45° to the incident ray, and place your eye at table height so as to receive the emergent ray. Look into the prism. Can you see an image of the slit? Is its location related to the direction of the incident, refracted or emergent ray? It



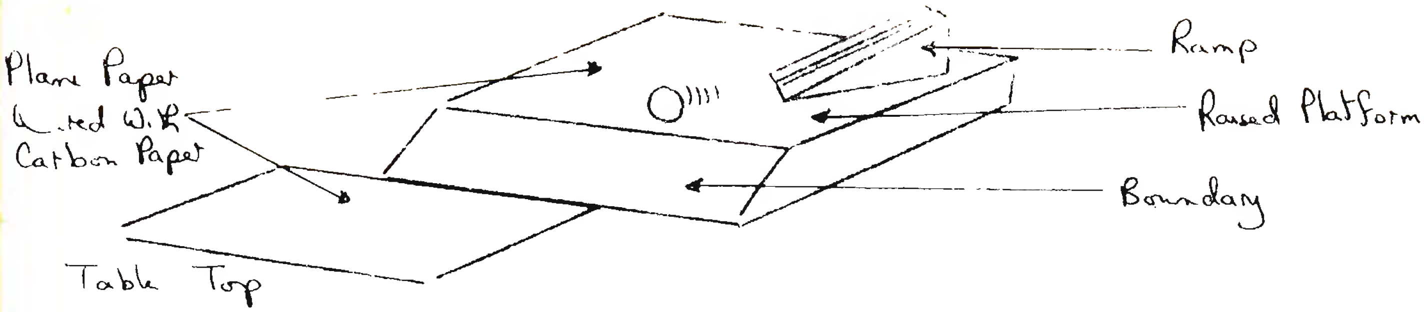
is possible to view the slit and its image simultaneously. Do the image and slit appear to be in line with one another? What happens to the image position as you decrease the angle between the incident ray and the front surface of the prism?



(iii) Newton developed a very simple theory to explain why light was refracted as it crossed the boundary from air into glass, and it is of interest to consider his arguments. Let's represent the velocity of the incident ray's particles as having a horizontal (v_1) and vertical (v_2) component. Newton believed that when light particles reached the boundary between the two media they were acted upon by a force at right angles to the boundary. This force was capable of acting alternately as a force of repulsion (F_1) and then as a force of attraction (F_2). The force of repulsion reversed the direction of the vertical component (v_2) giving rise to reflection, while the force of attraction increased the vertical component (v_2 to v_3) as the particles entered the medium giving rise to refraction. In both instances Newton indicated that the horizontal component of the velocity remained unaffected. Newton's theory therefore depended on the condition that the velocity of light in a medium such as glass would be greater than that of light in air.

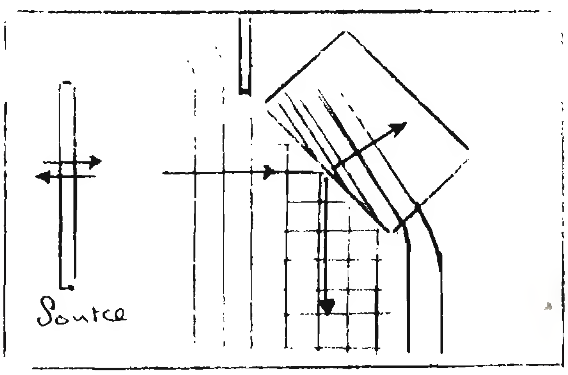


Take the refraction model apparatus available, and raise the main platform about 4 cms above the table top with books or blocks of wood. Place the small ramp at the back of the platform, and release the ball bearing from the top of the ramp so that it runs diagonally across the platform, down the sloping boundary and across the table top. Having observed the approximate direction of motion cover the platform and adjacent table top with plain sheets of paper, in turn covered with carbon paper, so that the direction of the rolling ball may be recorded accurately.



The velocity of the ball bearing should increase under the effect of gravity as it rolls across the boundary. Does the ball change its direction due to this change in velocity, and if so does the direction change support Newton's Corpuscular Theory?

The refraction of light as it moved from one medium to another was equally well explained by Huyghen's Wave Theory. We have already seen with the ripple tank that as waves move from a deep medium of water to a shallow medium they are refracted. We may compare our light entering a prism from air with waves entering a shallow medium of water from a deep medium in order to explain the refraction of light. Would the Wave Theory agree with the Corpuscular Theory by suggesting that the velocity of light in a prism must be less than that of light in air? Would you expect simultaneous refraction and reflection at the boundary of a medium if the Wave Theory is true? Do you see any conflict between the two theories?



Both Newton and Huyghens developed their respective theories around 1678. At the time there was no known method of comparing the velocity of light in various media. It was in fact 1850 before such a technique was established by Foucault. Had it been possible to measure the velocity of light in various media as early as 1678 would this have affected either of the theories?

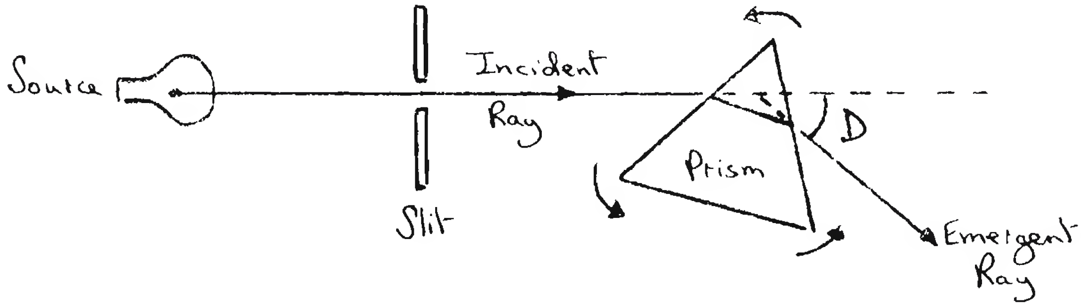
4.14 Color

Apparatus Required

Qu	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Slit/Aperture Combination	4.10/02
2	Triangular Prisms	4.10/05
2	Cardboard Screens	4.10/07
1	Filter (Red)	4.10/08
1 sheet	Plain Paper	

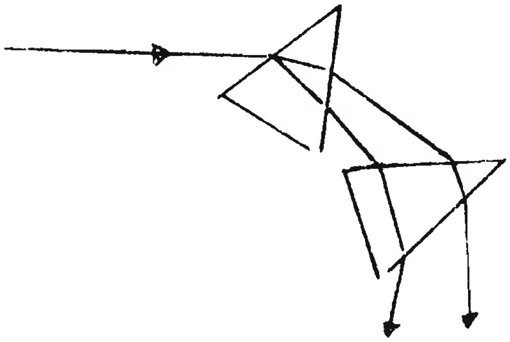
Activities

(i) Set up the slit some 7 or 8 cms from the light source so that the ray produced has almost parallel edges. Place the prism some 7 or 8 cms beyond the slit in the path of the light ray. Note the refractions and reflections that can occur at the different faces of the prism. Adjust the position of the prism so that the light ray is refracted at two adjacent surfaces as illustrated.

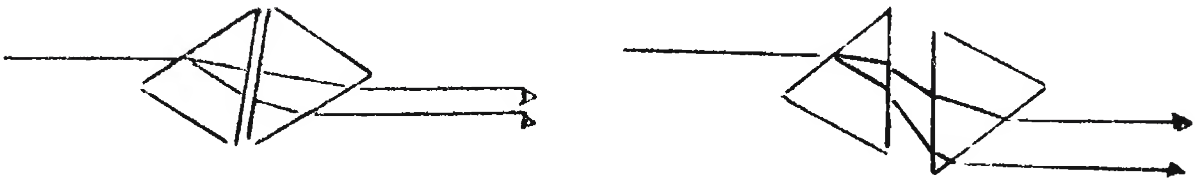


Obtain the maximum possible deviation (D) of the light ray by rotating the prism into a suitable position. Then slowly rotate the prism in an anticlockwise direction, and note the behavior of the emergent ray. Does the angle of deviation diminish continuously as the prism rotates? In the position of minimum deviation place the eye on a level with the table top, and look into the prism along the emergent ray. Do you notice anything of interest about the edges of the image or the edges of the emergent ray? In observing the emergent ray it is helpful to exclude excess daylight from the vicinity of the ray by using your hands or a book to create a shadow on the paper. (If you have any difficulty in seeing the complete image of the slit in the prism because of the way the rays slant downwards from the lamp to the table, place a second prism on top of the first to increase the field of vision.) Is there any relation between the colors you can see at the edge of the ray and those you see at the edge of the image?

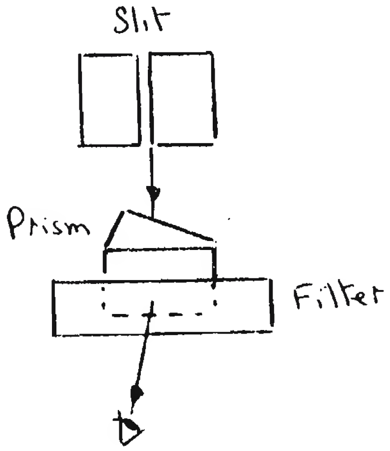
(ii) Set up the light source, slit and triangular prism just as in the above experiment to produce a strongly colored emergent ray from the prism. Place a second triangular prism in the path of the emergent ray so as to increase the deviation of the light even further. Is the ray which emerges still colored?



Now place the second prism in contact with the first so that the two prisms refract the light in different directions. Is the emergent ray still colored? With the prisms at the same angle to one another, gradually increase the distance between the two opposing faces. Can you explain what happens to the emergent ray?

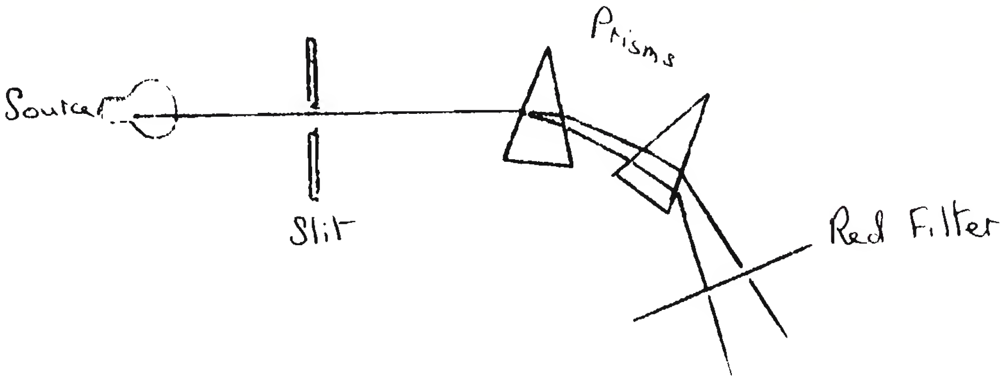


(iii) Take two black cardboard screens and place them against the laboratory window so that they form a vertical slit about one centimeter wide through which light enters. Stand about 4 meters from the slit and view it through the prism in the same way as you viewed the small slit on the table. Can you see a spectrum of colors? Get your partner to increase the width of the slit gradually from 1 to about 10 centimeters. What happens at the center portion of the slit image? Can you explain what you see?



Once more set the cardboard screens 1 cm apart, and view the slit through the prism in such a way as to create a clear spectrum. Then insert a red filter immediately in front of the prism so that the lower half of the spectrum is covered by the filter. Draw a diagram showing the upper and lower parts of the field viewed. What does the filter do?

You might check your conclusion by creating a spectrum with the light source and prism as in earlier experiments, and placing the filter in the path of the emergent rays. Does the red filter prevent any of the light rays from passing through it?



4.20 DIFFRACTION AND INTERFERENCE

So far our observations of optical phenomena have done no more than establish that the Wave Theory clashes with the Corpuscular Theory. It would be unscientific to claim that our evidence shows one theory as being superior to the other. We may have some doubt about Newton's explanation of simultaneous reflection and refraction, but we probably have similar doubts about the Wave Theory's explanation of light rays always travelling in straight lines. In fact, if the Wave Theory is to enjoy any support whatsoever, it is imperative to try to show that light can bend around corners under suitable conditions.

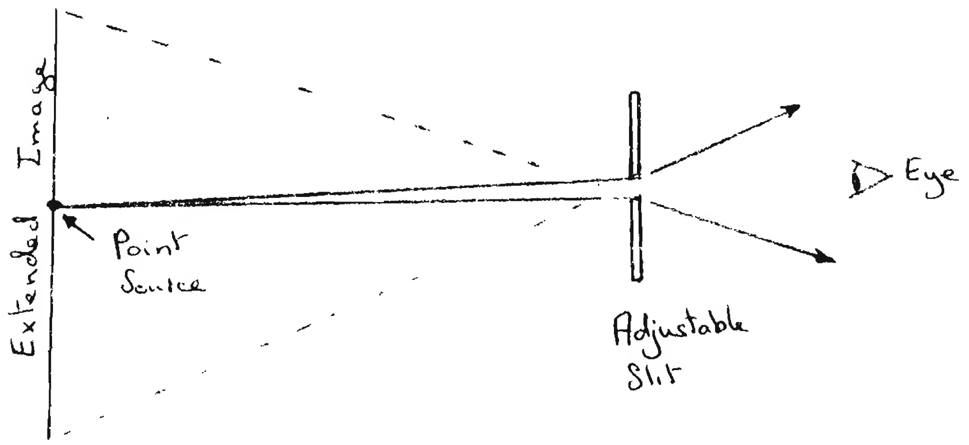
4.21 Diffraction

Apparatus Required

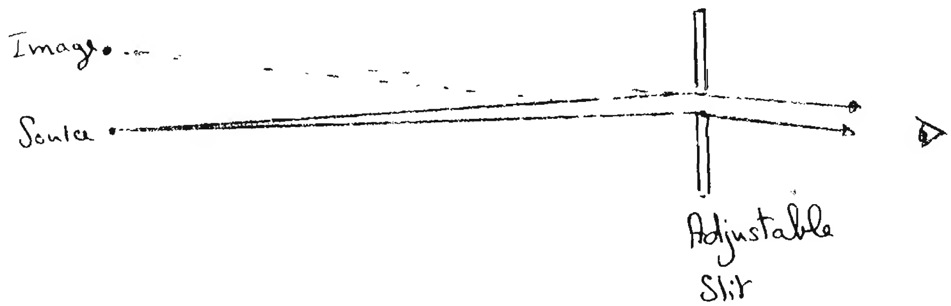
Qu	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Adjustable Diffraction Slit	4.20/01-02
1 set	Simple Diffraction Holes	4.20/03
1	Filter (Red)	4.10/08

Activities

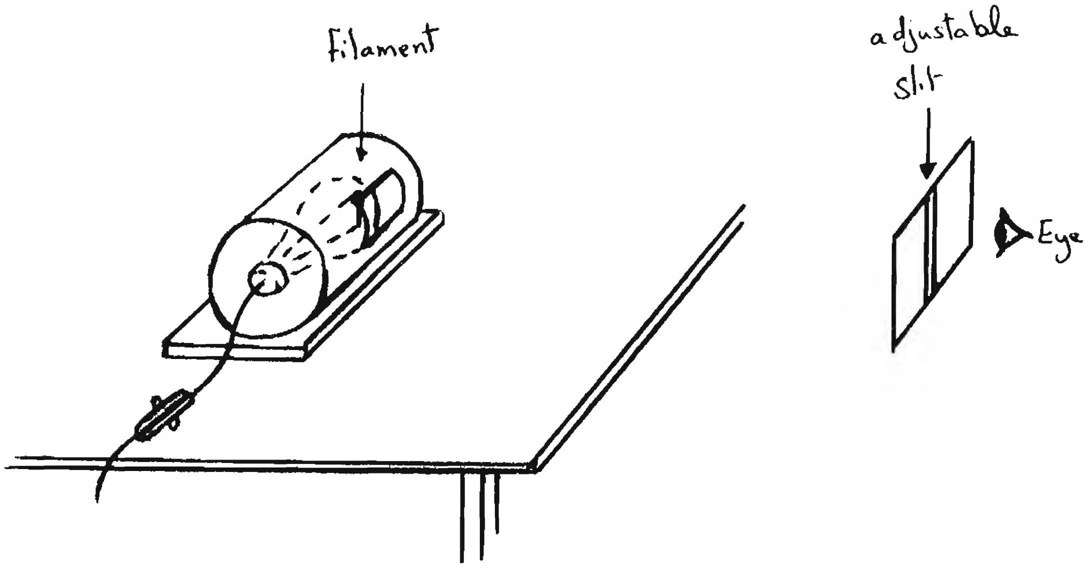
(i) If light behaves as a wave motion it would seem that it should be possible to make it spread out from an aperture, if we can make the latter small enough. Let's consider rays (from a point source) which fall on such an ideal aperture. If the rays bend outwards from the aperture they will appear to emerge from an image of the source, the image being much wider than the source. Therefore instead of seeing an identical image of the filament we might expect to see an extended image of the filament.



Of course, if some other phenomenon such as refraction occurs, we would expect to see an image of the filament displaced to one side of the filament.

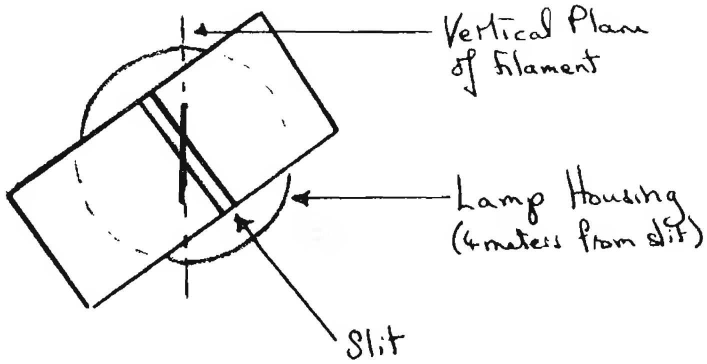


Now let's see what really happens, and try to interpret our observations. Set up the light source so that its filament is vertical, and view it at a distance of about 4 meters through an adjustable slit, held in the same vertical plane. Reduce the width of the slit until its edges are almost touching. What do you observe? If you reduce the width of the

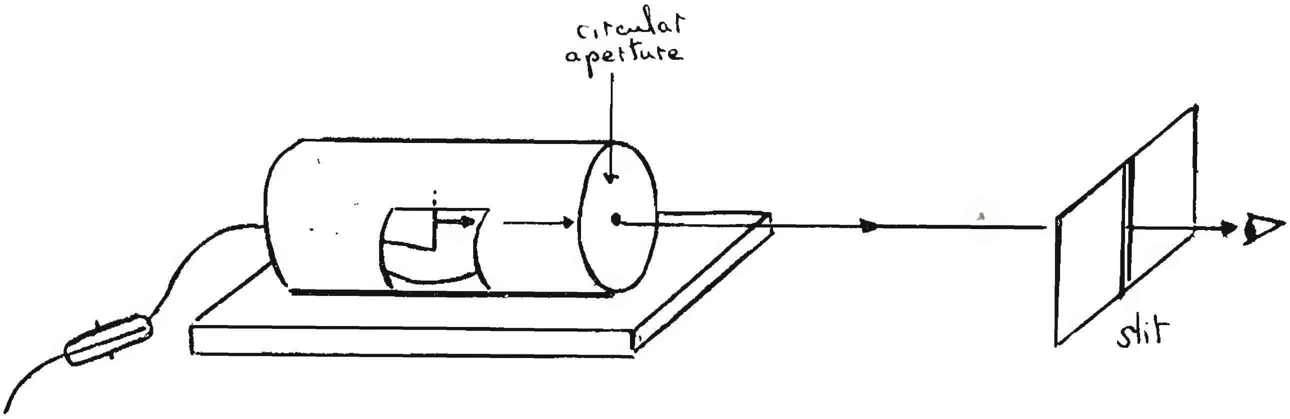


slit what happens? Do your observations in any way relate to what you might expect if light behaves as a wave motion. Repeat the experiment with a red filter placed over the adjustable slit. Explain what happens.

(ii) Once again view the vertical filament of the light source through a slit at about 4 meters from the filament. However, this time hold the slit at varying angles to the vertical. Are bands produced parallel to the source or to the slit? What effect does rotating the slit have on the pattern produced?



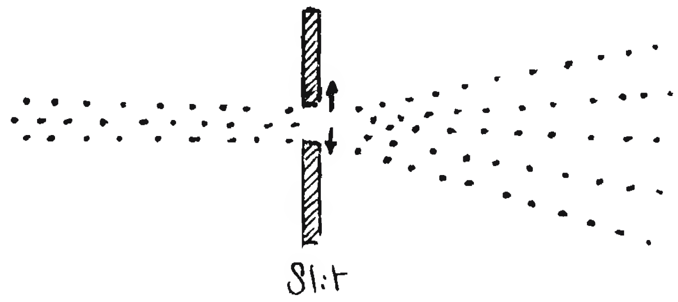
(iii) Try replacing the vertical line source used in the above experiment by a circular point source to see if this affects the type of diffraction pattern viewed through a slit. This may be done by simply rotating the light source so that you view the filament directly through a small hole drilled in the lid of the lamp house. The source will no longer appear as a line, but as a point. Now view the source through the slit from a distance of 4 meters or more. Hold the slit at varying angles to the vertical. Record the nature of your observations.



Replace the slit by each of the simple diffraction holes in turn. Is the pattern observed different from those previously noted with the slit?

Finally, it is well worthwhile repeating your observations on a much larger scale with brighter sources placed at greater distances from the slit or aperture. This can be done quite easily if you take your slit and aperture home with you one evening. When it gets dark go for a walk, and use your slit (and aperture) to view any available light sources such as street lamps, neon bulbs or any similar source. If you can't find electric lamps in the vicinity, the moon will act as a very nice source.

(iv) Newton explained the bending of light rays by suggesting that light particles were attracted towards the sides of the slits and apertures because of an attraction between the masses involved. This explained the bending and spreading of light rays, but it did not explain the bright and dark bands associated with the pattern produced.



Huyghens explained the bending of light at slits and apertures simply by indicating that light must be a wave motion. He also developed a theory to explain the bright and dark bands observed within the pattern, and this theory is developed in the following activities.

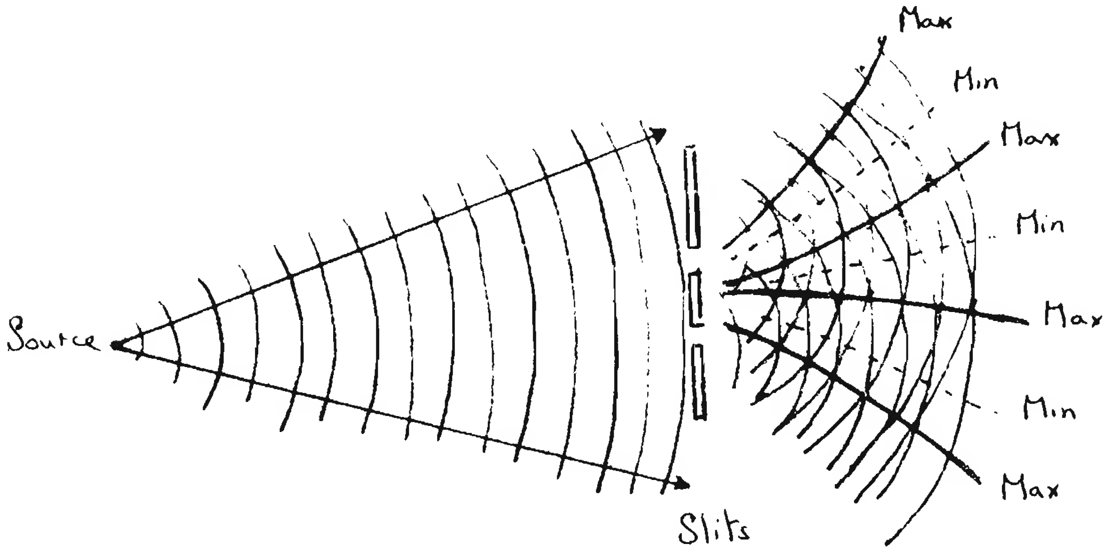
4.22 Interference

Apparatus Required

Qu	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Adjustable Diffraction Slit	4.20/01-02
1	Filter (Red)	4.10/08

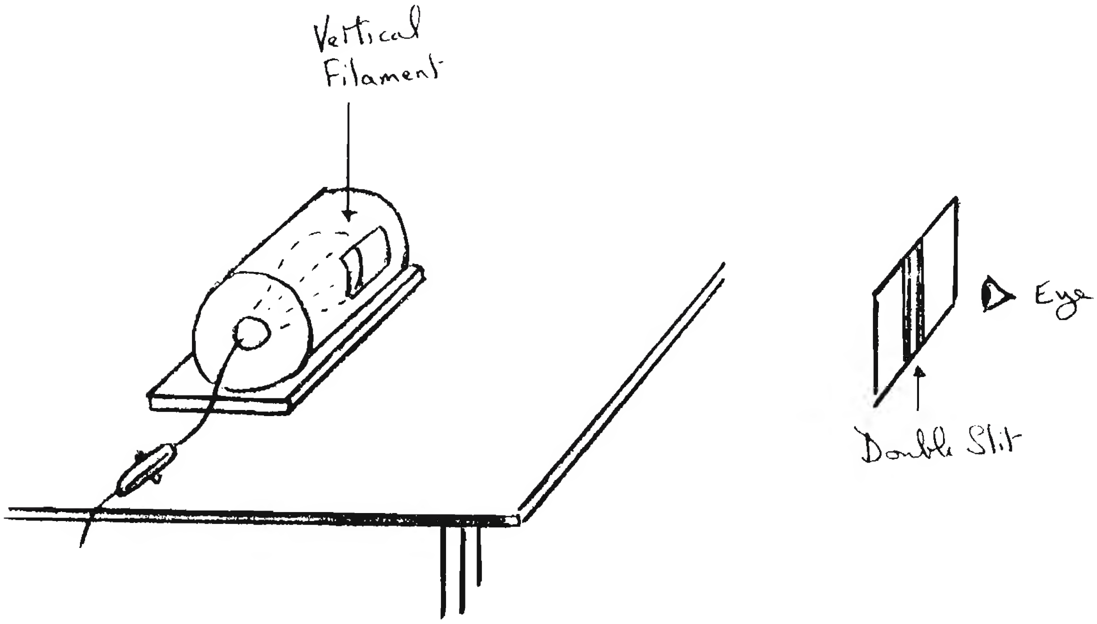
Activities

(i) Let's start once again by theorizing, and then test that theory out. If light is transmitted as a wave motion we should be able to produce some phenomenon similar to the interference effect observed in the ripple tank. We might hypothesize that if light spreads out from a point source and strikes two adjacent apertures, the light will spread out from the two apertures as two new wave motions, assuming the apertures are sufficiently small, and we might theorize that these two motions might interfere with one another if the apertures are close enough together. We have introduced a lot of 'ifs' into our comments. However, assuming these conditions could be met we would expect to be able to produce strong lines of maximum disturbance moving forward with the wavefronts and lines of minimum disturbance



in between. We might equate a motion of strong disturbance to bright light and a motion of minimum disturbance to minimum light, or darkness. Clearly we would expect to produce dark and bright bands.

Let's now test out this hypothesis. Set the light source up with its line filament vertical. Hold your double slit vertical and close to your eye, and view the filament through it when the latter is about 4 meters away. Do you see dark and bright bands? Place a red filter over the slits.



What effect does this have? Now cover one of the slits with the edge of a sheet of paper. Is the resultant pattern familiar? When you remove the sheet of paper and view the filament once again through the two slits can you see anything resembling the pattern of a single slit still? Draw a diagram comparing the pattern produced by one of the two slits on its own with that produced by two slits acting together.

Newton could not explain this phenomenon by means of the Corpuscular Theory. Do you feel that the Wave Theory offers a plausible explanation of what you have observed?

Despite findings such as these, the world's physicists remained divided over the two light theories until 1850 when Foucault designed apparatus to measure the velocity of light. It was then discovered that the velocity of light was greater in air than in a dense medium such as glass or plastic. You might review your experiments on light at this stage and see why this finding settled the argument in favor of the Wave Theory.

4.30 FURTHER OPTICAL PHENOMENA

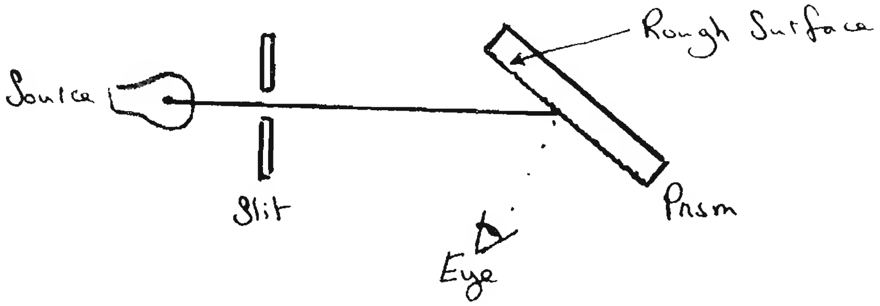
4.31 Scattering of Light

Apparatus Required

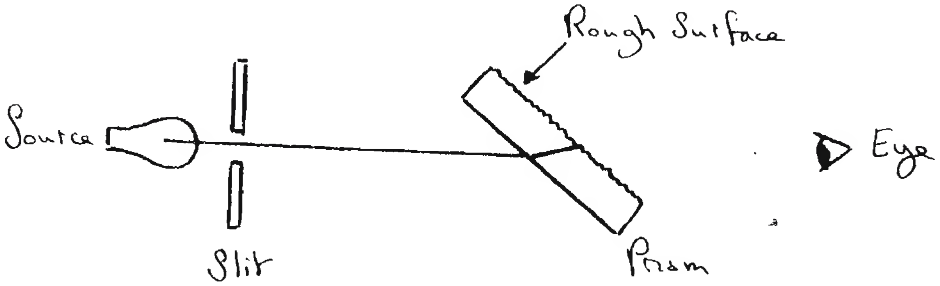
Qu	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Slit/Aperture Combination	4.10/02
1	Rectangular Prism	4.10/05
1	Plastic Container	
1 sheet	Plain Paper (30 x 20 cms)	

Activities

(i) Take the rectangular plastic prism, and feel the prism's various surfaces. One surface has been roughened deliberately with fine carborundum paper. Place the prism on a sheet of plain paper, and position it so that the ray of light emerging through a slit from the light source falls on the roughened surface. Study the reflection which occurs at the surface. Do you see a single reflected ray which leaves the prism so that the angle between the prism and the ray is the same as that between the incident ray and the prism surface? Look into the surface of the prism. Do you see a clear image of the slit?

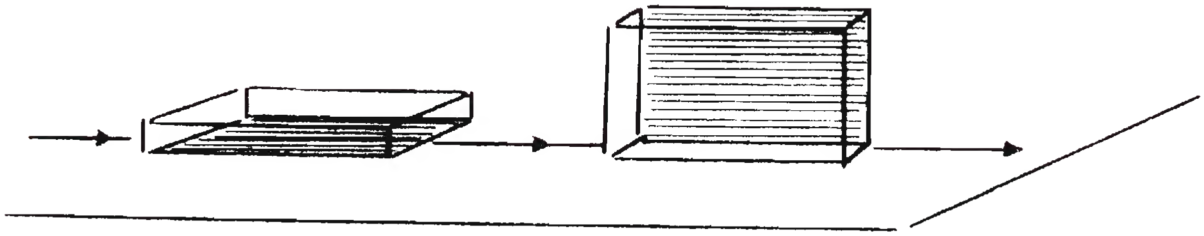


Now turn the prism around so that the ray of light strikes the smooth surface first and is then transmitted through the prism to the rough surface. Does a single ray emerge clearly from the prism? Looking into the prism can you see a clear image of the slit related to the emergent ray? Can you explain what you have observed?

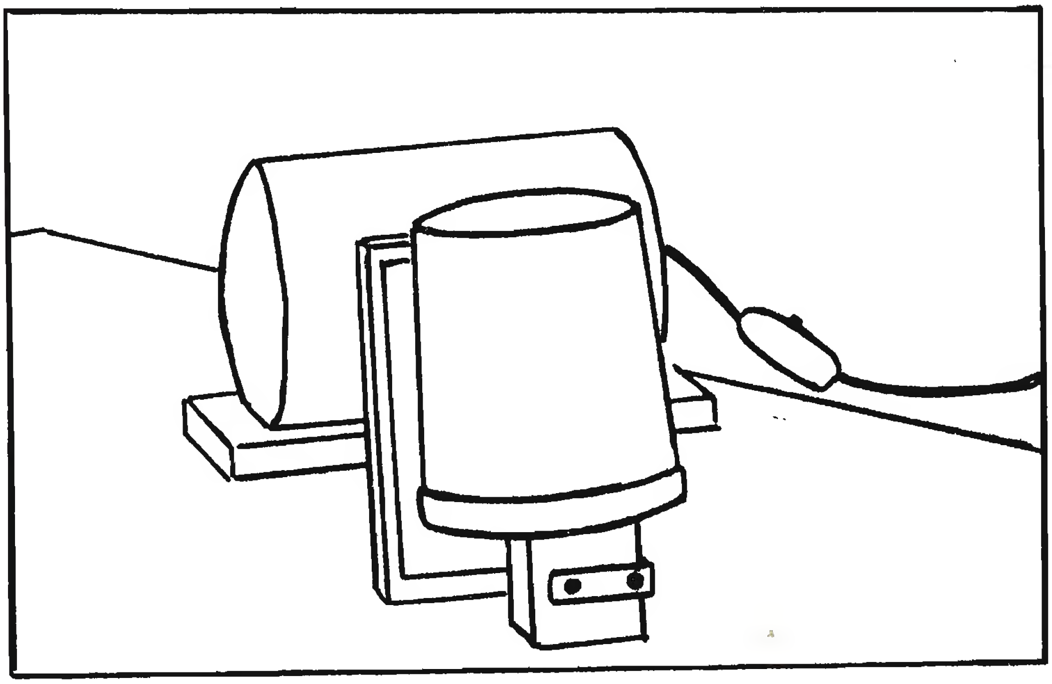


In previous experiments with the rectangular prism, whenever it was considered desirable to trace rays of light through the prism, care was taken to have the rough surface of the prism (not the smooth surface) in

contact with the paper on the table top. Can you now explain the reason for this?



(ii) A clear plastic container is filled with dense smoke. A cigarette, a smouldering piece of cloth or a recently extinguished candle, all provide suitably dense smoke. A ray of light from the lamp is passed through the slit into the container. Look into the container from different angles (front and sides), and note what you observe. Can you explain what you see?



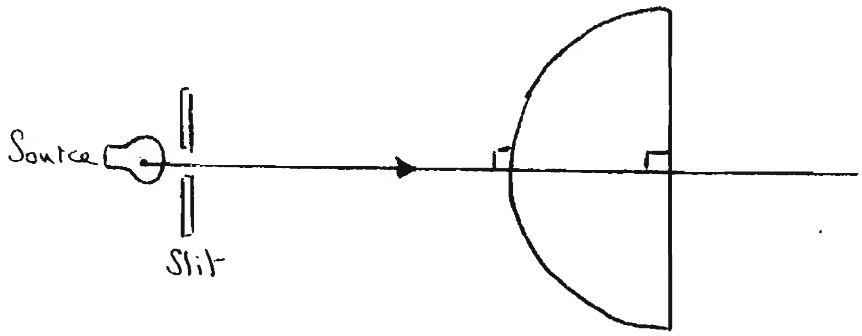
4.32 Total Internal Reflection

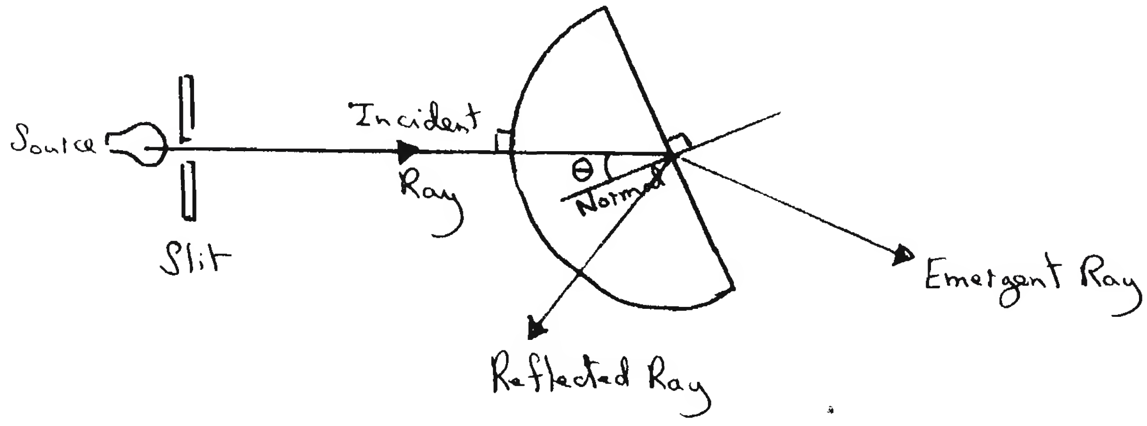
Apparatus Required

Qu	Apparatus	Item No.
1	Semi-circular Prism (Lens)	4.10/05
1	Triangular Prism	4.10/05
1	Rectangular Prism	4.10/05
1	Protractor	
1 sheet	Plain Paper (30 x 20 cms)	

Activities

(i) With the help of a light source and slit cause a ray of light to cross a plain sheet of paper and strike the curved surface of a semi-circular prism. Place the prism in such a position that the ray strikes the front and rear surfaces of the prism at right angles to the surface. In this position the light will not be refracted at either surface. Now rotate the prism in such a way that the light still strikes the curved surface at right angles but strikes the rear surface at an angle (θ) to the normal (a line drawn at 90^{o} to the surface).



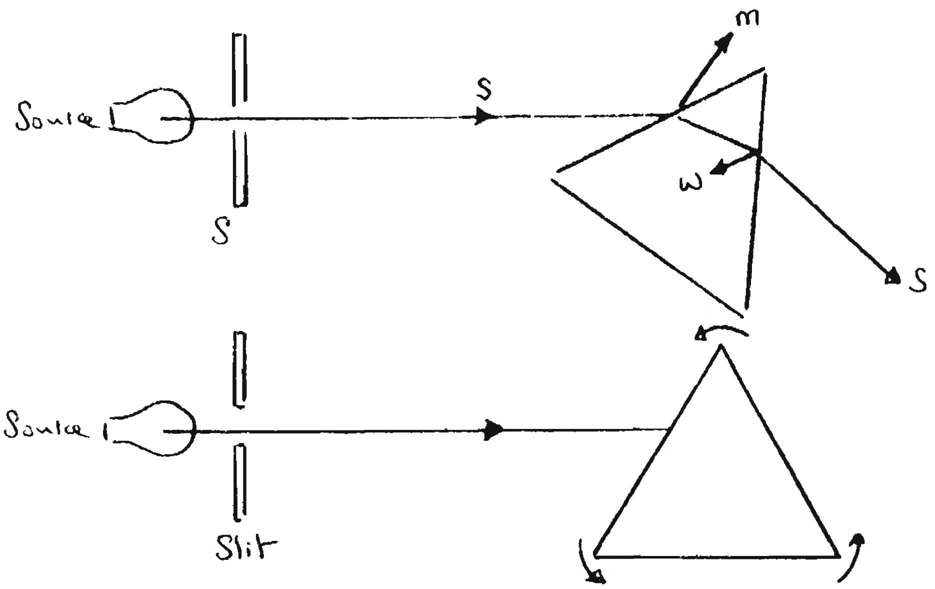


Carefully record what happens to rays striking the rear surface when the angle (θ) is fixed first at 30^{o}, then 40^{o}, 45^{o} and 50^{o} degrees.

For this series of observations you will find it helpful to make an outline of your semi-circular prism on the paper beneath it. If you mark the middle of the straight edge it is a simple matter to draw further lines through the same mid-point such that they are inclined at angles of 30°, 40°, 45°, and 50° degrees to the original straight edge. If the straight edge of the prism is placed on each of these lines in turn, keeping the curved edge on the same curved line, the angle (θ) created between the incident ray and the normal to the surface will automatically take on the values proposed above.

Are you able to record a reflected ray and an emergent ray in each and every instant?

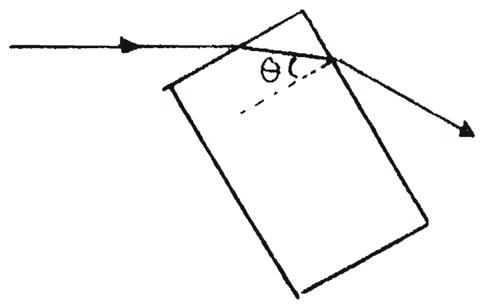
(ii) Take a triangular prism, and place it in the path of an incident ray, so that light is refracted through the prism as indicated in the diagram below. Then slowly rotate the prism in an anticlockwise direction noting the behavior of all the rays, particularly the emergent ray, as the



prism rotates. Record the directions of the various rays for various prism positions, indicating the strength of the rays (S = Strong, M = Medium, W = Weak) in each case. What happens to the emergent ray? Can you explain this in terms of the Critical Angle (θ_c) of the prism?

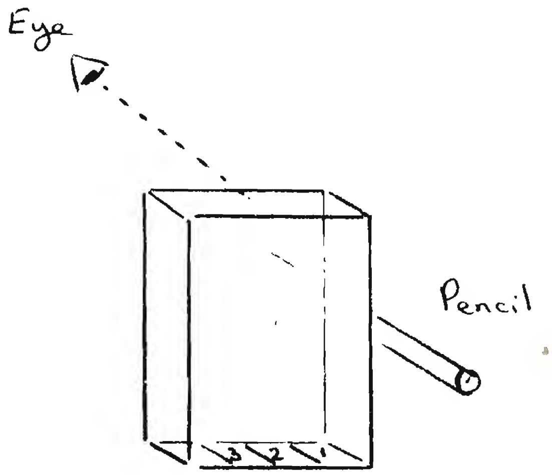
Is the Critical Angle for a triangular plastic prism the same as the Critical Angle for a semi-circular plastic prism?

(iii) With the help of the light source and slit·is it possible to make a ray of light enter one side of a rectangular prism and emerge by the adjacent face?



Trace the position of the prism on the paper placed beneath it. Draw in the directions of the incident ray striking the first surface and the refracted ray striking the second surface. Measure the angle (θ). Rotate the prism and repeat your observations for several positions of the prism. Can you explain what you observe in terms of the Critical Angle of the prism?

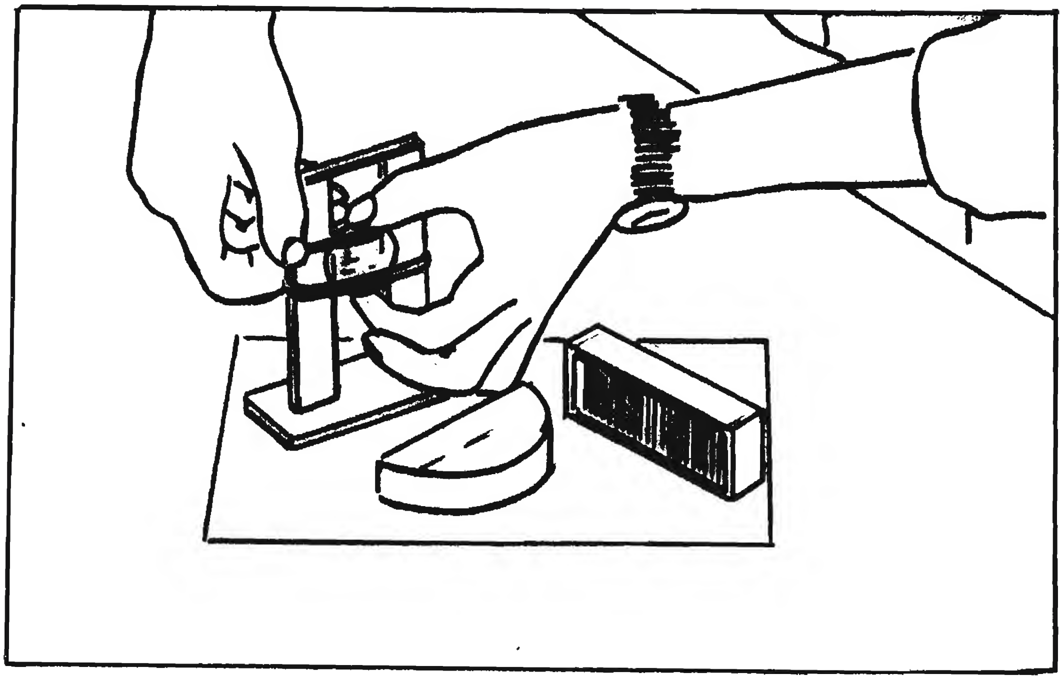
(iv) Stand the rectangular prism vertically on a sheet of white paper so that it covers three separate distinguishing marks such as the numbers 1, 2 and 3. Looking at an angle of about 45 degrees into the top surface of the prism can you see the marks beneath the prism?



Looking through the same top surface can you see a pencil placed behind the adjacent vertical side? Does it make any difference to your observation if you press the pencil close to the vertical surface? Finally, instead of pressing the pencil against the vertical surface press a finger against it. Can you explain how the clear finger print is produced?

4.33 Refraction by Lenses

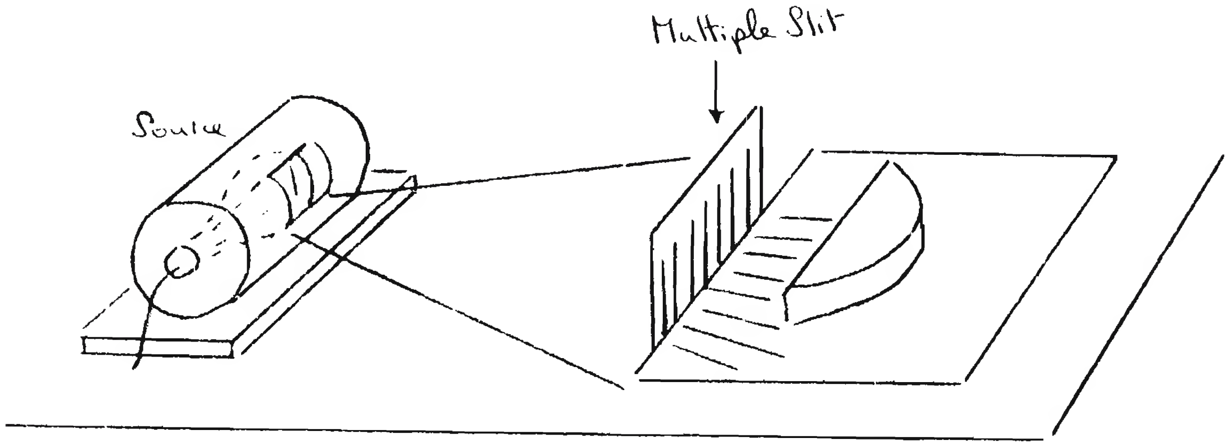
Apparatus Required

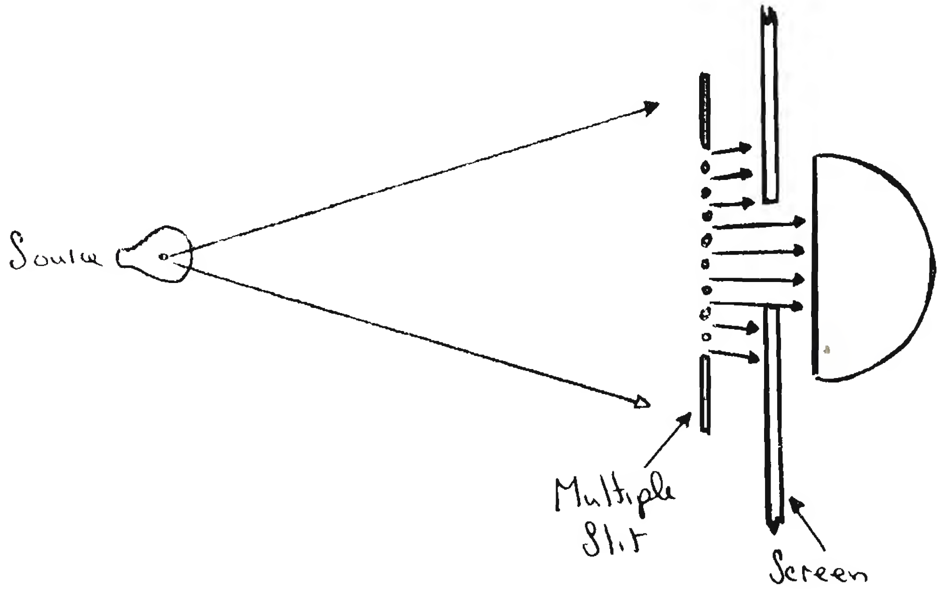


Qu	Apparatus	Item No.
1	Light Source with Base	4.10/01
1	Slit/Aperture Combination	4.10/02
1	Multiple Slit	4.30/01
1	Semi-circular Prism	4.10/05
1	Lens Holder	4.30/02
1	Hand Lens	
2	Screens	4.10/07
1	Meter Rule	
1	Set Square	
1 sheet	Paper	

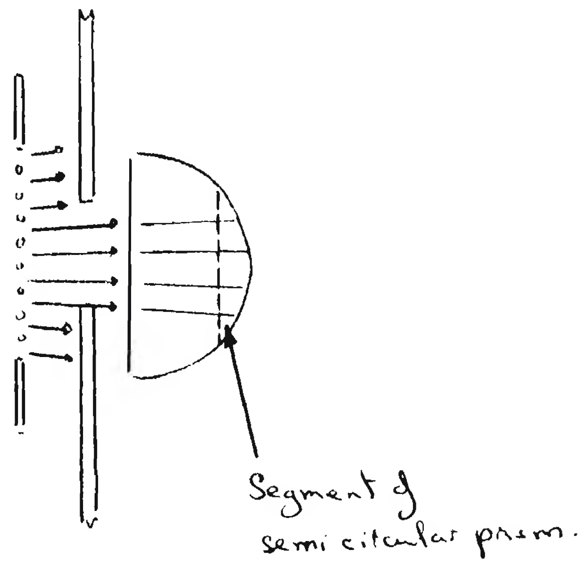
Activities

(i) Place the semi-circular prism on a sheet of paper about 40 cms from the light source. Notice how the light is refracted through the prism. Observation becomes more meaningful if a multiple slit is placed about 10 cms in front of the prism so that light rays from the source can be traced through the prism. Trace the rays that pass through the prism. Try eliminating the rays that use the outer part of the prism by blocking the paths of the rays with the cardboard screens. What effect does this have on the rays transmitted?

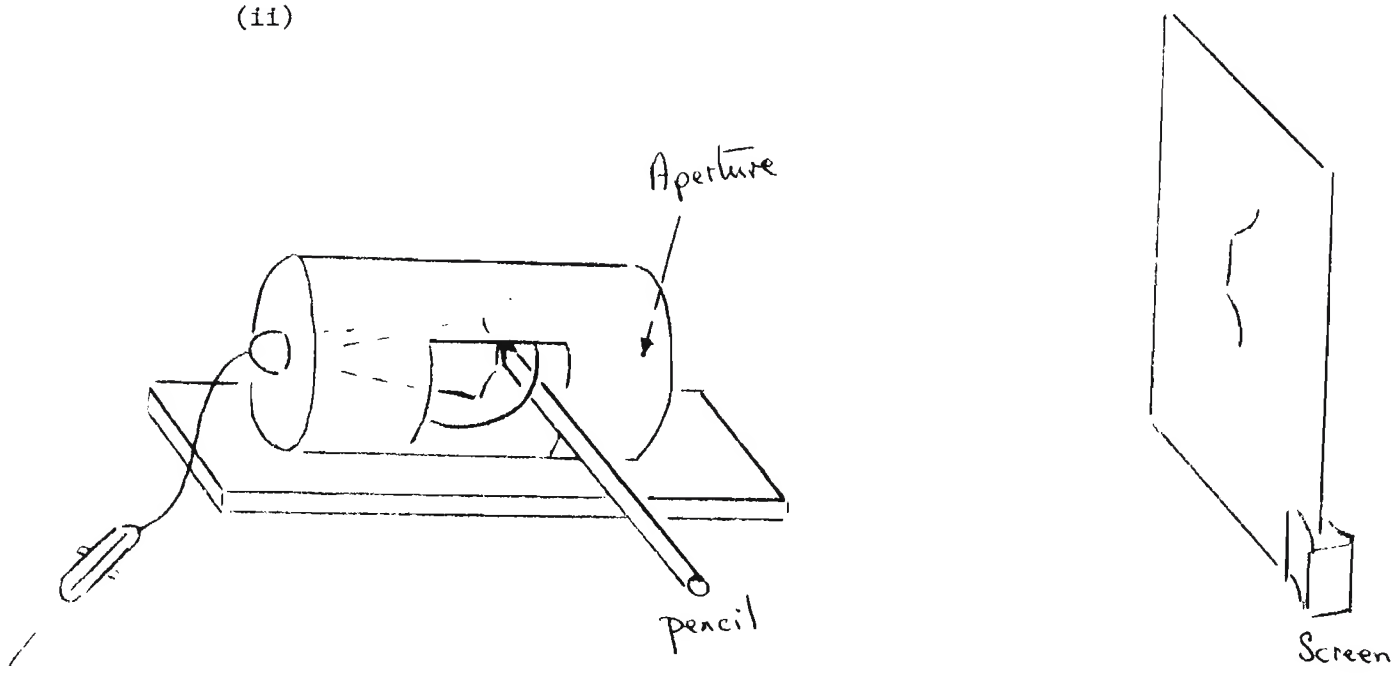




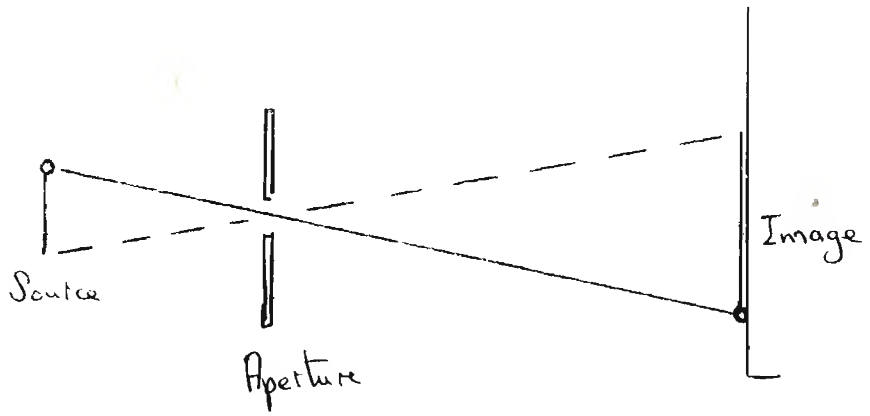
Would you expect any similarity in behavior between a lens and the semicircular prism? Can you suggest why lenses are segments of spheres, rather than complete hemispheres?



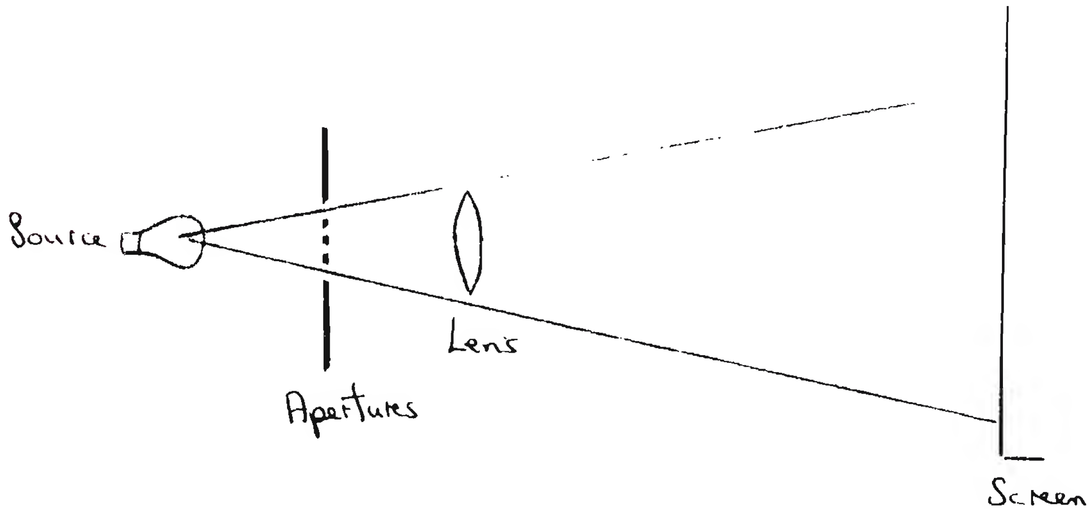
(ii)



Turn the light source so that light from the filament passes through the pin hole aperture in the lid onto a white, vertical screen. (For this experiment it is preferable to use a lamp with a crooked filament). Carefully note the shape of the filament, and then observe the shape of the image of the filament created on the screen. If you place a pencil close to the filament you can blot out rays of light being emitted from its lower parts. What part of the image disappears? Can you explain this with the help of the diagram below?

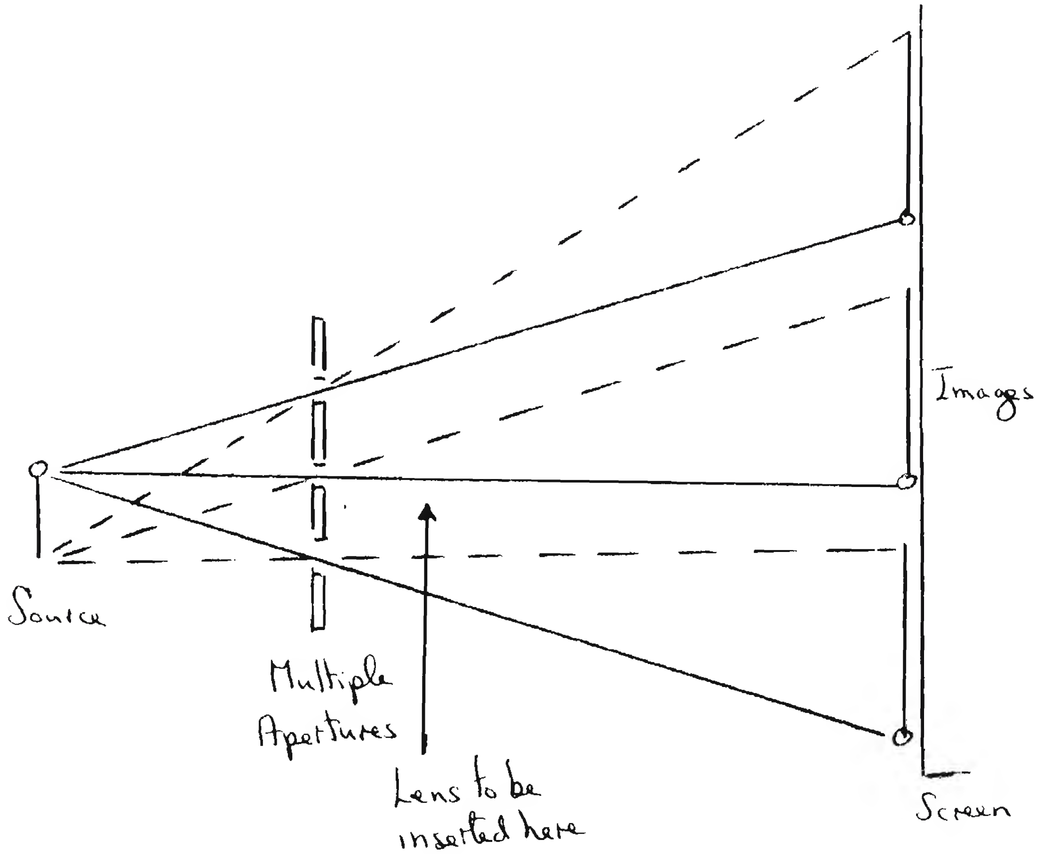


(iii) Take the lid off the lamp housing, and place the slit/aperture combination in front of the lamp so that the light passes through the apertures and on to a screen some 30 cms away from the source. Effectively we have simply replaced a single aperture in the above experiment by several apertures close together. Do you still have a single image of the filament on the screen?

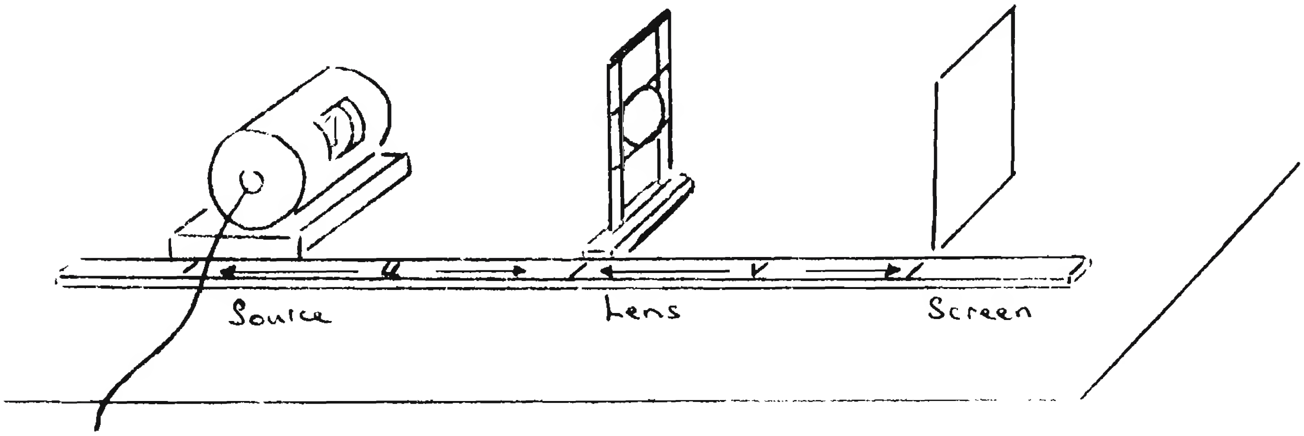


Take the lens provided, and place it directly in front of the holes so that most of the light has to pass through the lens before reaching the screen. Move the lens slowly towards the screen observing the behavior of the images produced. Is there a position of the lens which creates a very clear image of the filament? Can you find more than one such position? If you find a position of the lens which gives you a clear image of the filament on the screen see what happens to the image in that position when you remove the apertures away from the front of the light source.

With the help of the diagrams below can you explain satisfactorily to yourself how images are formed by multiple apertures? If so, try to develop the logic further to explain the image you produced with the help of the lens.



(iv) Set the lens up in the stand provided so that it is at the same height as the filament of the light source. Place the lens about 10 cms from the filament, and adjust the position of the screen to obtain a sharp image. Measure the object distance 'u' between the object and lens, and the image distance 'v' between the lens and image. Increase the object distance step by step to 40 or 50 cms measuring the new image distance in each case. Does the image distance appear to depend on the object distance?



Increase the object distance to 70 cms and then 90 cms, and measure the new image distances.

Finally, use light from the window as a source. Stand 4 or 5 meters away from the window and see whether using your lens you can obtain an image of the window on your screen. Measure the image distance. Is there anything special about the image distance for sources a long way from the lens, say 3, 4 or 5 meters, or more?

4.34 Formation of Interference Colors

Apparatus Required

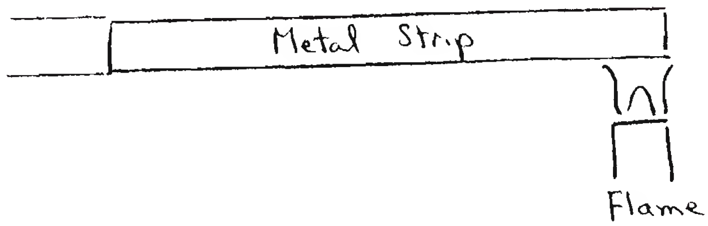
Qu	Apparatus	Item No.
1	Ripple Tank	3.10/01
2	Interference Strips	4.30/03
1	Soap Bubble Holder (Wire Loop 4 cms diameter)	
	Olive Oil	
	Soap Solution	

Activities

(i) Take your ripple tank outside and make sure it is thoroughly clean by washing it with soap and water. Then set it up (preferably over a dark surface, rather than a bright one such as concrete), and fill it with clean water to a depth of about 1 cm. Using a steel wire transfer a single drop of olive oil to the surface of the water, and watch the pattern created as the drop spreads outwards on the surface. Have you seen similar patterns before? Can you guess at the type of phenomenon involved.

(ii) You might repeat an old childhood game of blowing soap bubbles with the circular wire framework and soap solution provided. This time look carefully for the creation of optical patterns in the bubbles. This experiment is also best conducted outside in bright sunlight. Observations can be guided into a more controlled experiment if, instead of blowing a soap bubble, you leave the soap film on the wire framework. Hold the frame vertically so that the soap solution will drain gradually towards the bottom of the frame. Look carefully into the soap film for familiar patterns. Do you recognize any?

(iii) Take the copper interference strip, and having cleaned it thoroughly with sandpaper hold one end in a hot flame. Do you notice any color changes in the metal? Repeat the process with the steel interference strip.

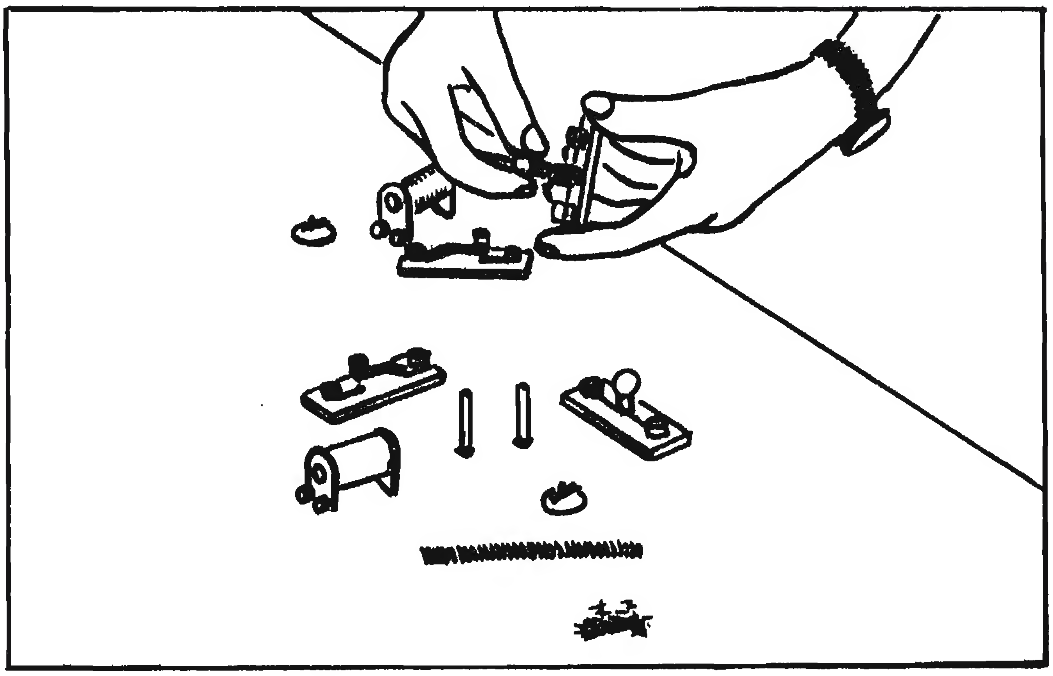


5. ELECTRICITY

5.10 ELECTROMAGNETISM

5.11 Magnetic Effects of an Electric Current

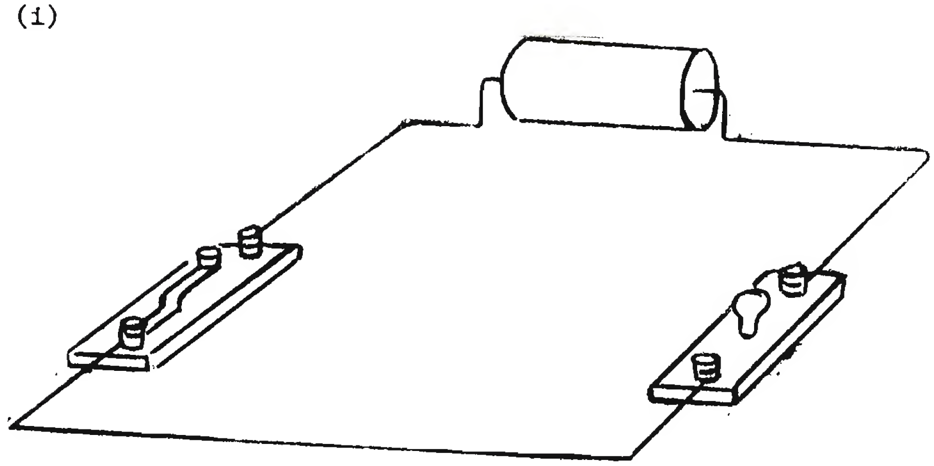
Apparatus Required



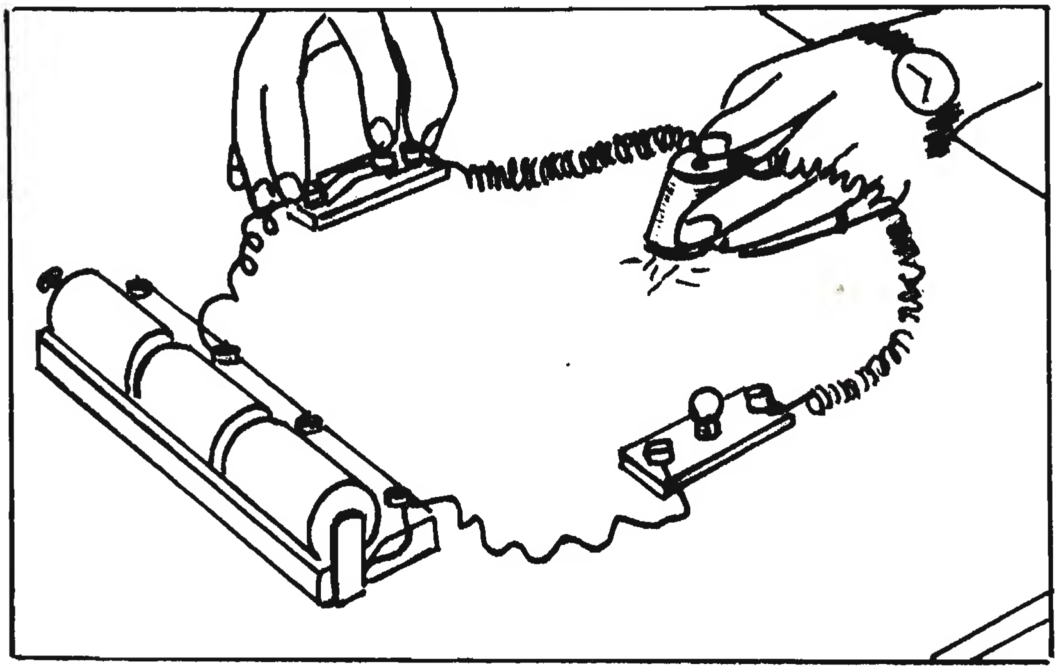
Qu	Apparatus	Item No.
1	Dry Cell Holder with Cells (3 cells, each 1.5 volts)	5.10/01
1	Bulb Holder with Bulb (2.5 volts, 0.3 amps)	5.10/02
1	Switch	5.10/03
1	Multipurpose Coil with Cores	5.10/04
2	Compasses	5.10/05
4 meters	Magnet Wire (#24, with both ends bared)	
1	Nail (10 cms long, 0.7 cms diameter)	
50 pieces	Soft Steel Wire (0.5 cm lengths from paper clips)	
1	Steel Wire (7 cm length, 0.1 cm diameter, e.g., straightened out paper clip)	
15 pieces	Connecting Leads (plastic or cotton covered #24 copper wire; 5 pieces each 5 cms long; 5 pieces each 25 cms long; 5 pieces each 100 cms long	

Activities

(i)



Take a dry cell (1.5 volts), a small bulb (2.5 volts, 0.3 amps) and a switch, and connect them in series into a cicuit. Press the switch. You have now made a simple electrical circuit similar to that used in a flashlight. Such electrical circuits can produce extremely interesting phenomena, and it is our intention to study some of these closely. However, one word of warning. Always use a switch in the circuit, and never press the switch for longer than is necessary, otherwise you will find your dry cells wearing out extremely rapidly.



Add the multipurpose coil provided to the circuit, inserting a soft iron core into the coil. Hold the coil vertically above a number of small pieces of steel wire (each 0.5 cms long), and switch on the current. Is it possible to attract the wire? What happens when the current is switched off? Repeat the experiment with 2 cells connected end to end, instead of one. Is there any difference in the attractive power of the coil and core? Can you explain what you have observed? It will help you if you compare the effect on the coil with that on a light bulb in a similar circuit.

(ii) With the circuit the same as for the last experiment replace the soft iron core by a hard steel core, and repeat the experiment with 2 cells in the circuit. Do the coil and core still attract the pieces of wire? What happens to the wire when the current is switched off?

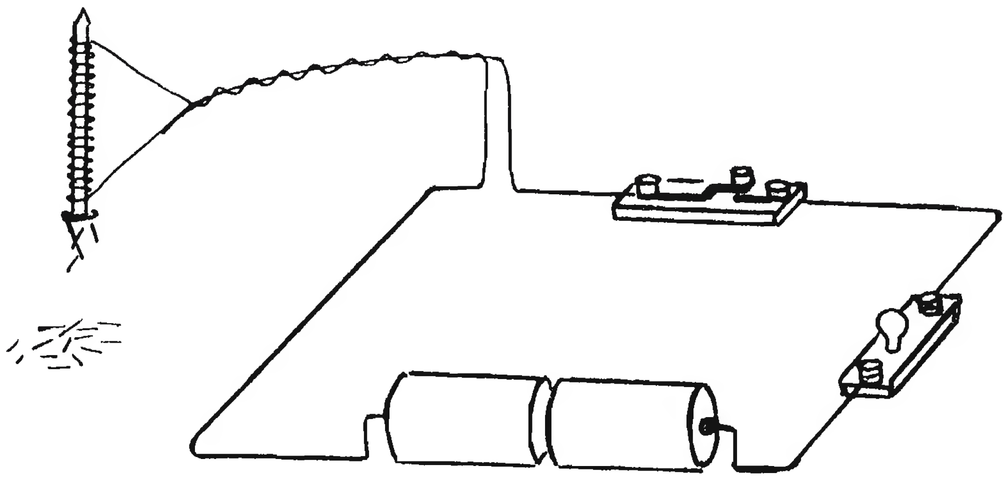
Take the core out of the coil, and hold it above the small pieces of steel wire. Does the core show any power of attraction? Repeat the experiment with the soft iron core. Does this have any attractive power once it is removed from the coil?

We generally refer to this phenomenon of attraction as magnetism. Iron cores can clearly exhibit magnetic powers of attraction when subjected to the influence of electrical currents. If a core takes up magnetism temporarily we say it becomes a temporary magnet, while if it takes up magnetism permanently it becomes a permanent magnet. What type of magnetism is created in the cores used in the investigation, temporary or permanent?

(iii) Take the 4 meter length of magnet wire provided, and wind it on to a nail to form a single layer of turns about 3 cms long. To prevent the coil from slipping thread the wire through itself to make the first turn, and having wound the coil tightly on the nail, twist the wire from

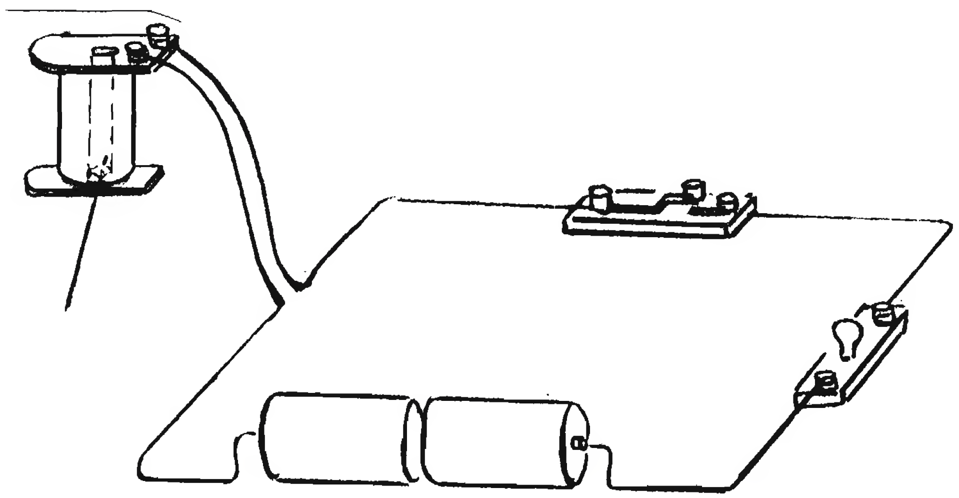
the ends of the coil around one another simply by twisting the nail.

Connect the coil into the circuit with 2 dry cells, a lamp, and a switch, and then see whether the improvised electromagnet has the power to attract any of the small pieces of steel wire provided. If it does, count the average number of pieces of wire it can pick up.



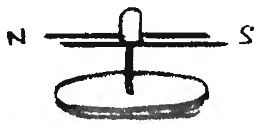
Increase the number of turns on the coil by adding a second layer of turns 3 cms long. Once again test the electromagnet, determining the average number of pieces of wire it can pick up. Finally repeat the experiment with a third layer of turns. Does increasing the number of turns on the core have any effect on the magnetic power?

(iv) The question must now arise as to whether a coil on its own, without a core, can produce magnetic attraction. To answer this question take the original coil provided, and insert it in the circuit along with 2 dry cells, a lamp, and switch. Hold the coil vertically (without an iron core) just above the small pieces of steel wire. Switch on the current, and observe whether there is any indication of magnetic attraction. What do you conclude? (Be careful as to how you state your conclusion).

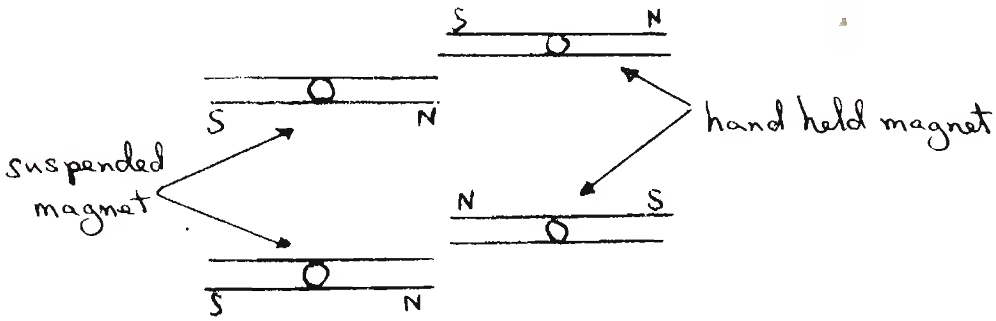


A slight variation in the last experiment might be performed, replacing the pieces of steel wire on the table top by a long piece of steel wire which is so close to the coil that it actually reaches inside it. This can be achieved by holding the coil vertically about 5 cms above the table so that the wire can be balanced in a vertical position, with the lower end resting on the table top and the upper end extending into the center of the coil. Complete the circuit by pressing the switch, and note what happens to the steel wire. What do you conclude?

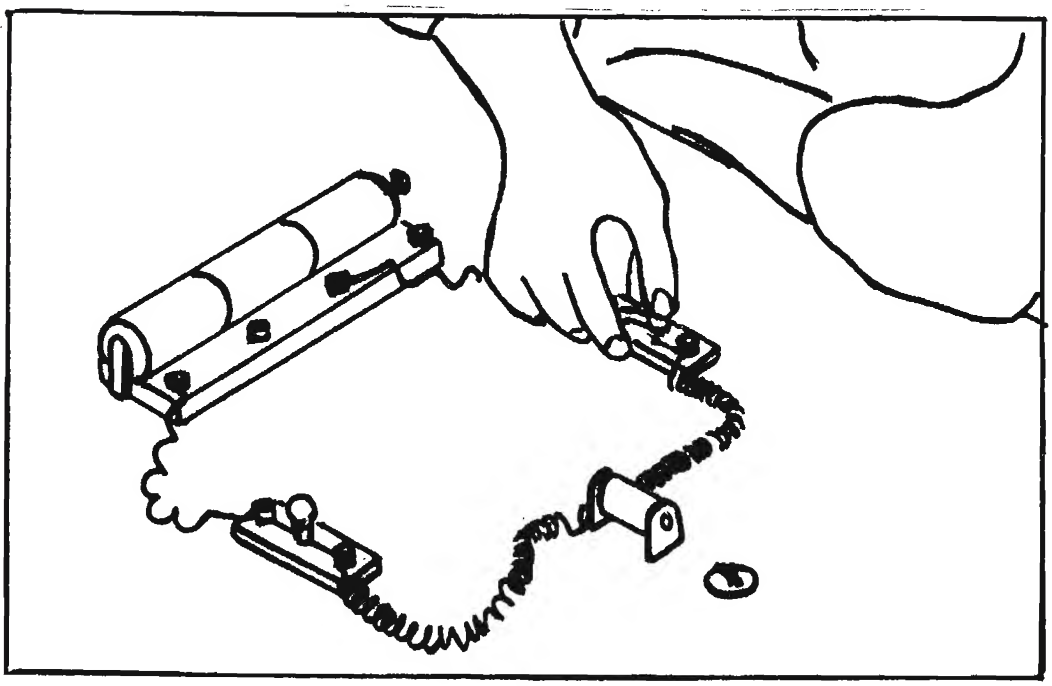
(v) A compass is simply a permanent magnet pivoted at its center so as to be free to rotate in a horizontal plane. Two such compasses are provided. It will be noted that the pivoted magnet (in this case two magnetized needles fixed side by side) always lies along a North/South line. Let's label the end of the magnet which points to the North as the North Pole of the magnet and the other end the South Pole of the magnet.



It is interesting to take one of the magnets off the pivot in order to hold either of its ends close to the ends of the pivoted magnet. First try holding the South Pole of the magnet close to the North Pole of the other. Then try holding the North Pole of the magnet close to the North Pole of the other. How do the poles affect one another? Does a South Pole affect a North Pole in just the same way that a North Pole affects a North Pole?



(vi) The above experiment might be repeated with the hand-held magnet replaced by a current carrying coil. To do this put the multi-purpose coil into a circuit in series with 2 cells, a bulb and a switch. Switch on the current and hold one end of the coil towards the compass (the pivoted magnet). Then without undoing any electrical connections hold the other end of the coil towards the compass. What do you observe?



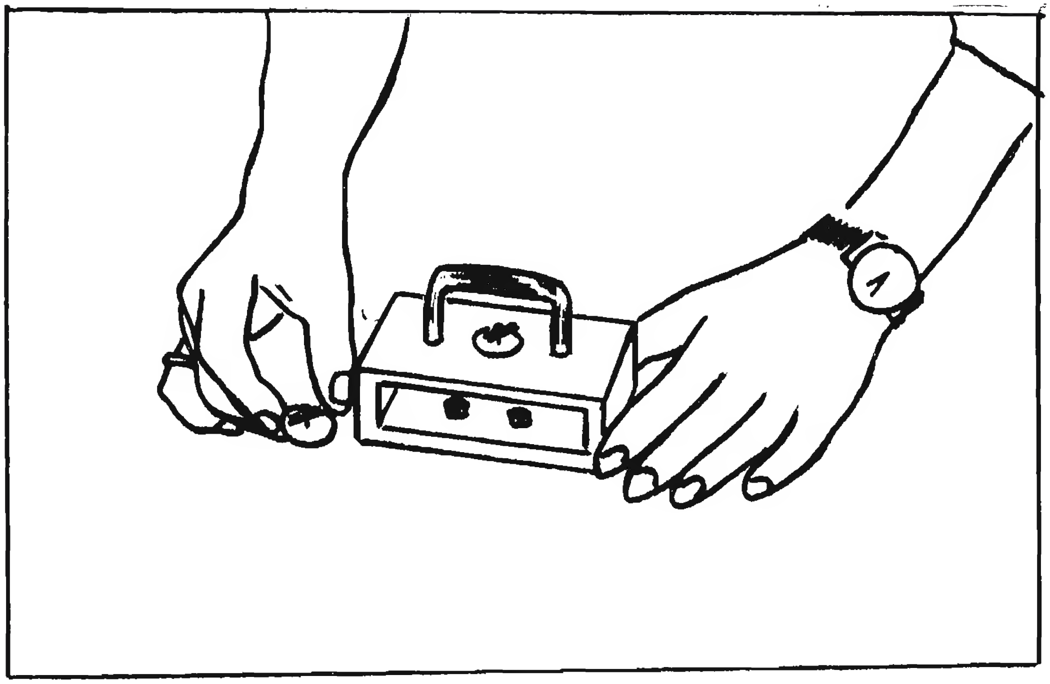
Does one end of the multipurpose coil behave like a North Pole of a magnet? If so take note of which end.

Now reverse the direction of the dry cells in the dry cell holder and repeat the experiment. Does the coil affect the compass needle in the same way as before? Does the same end of the coil behave like a North Pole of a magnet?

Take a close look at your dry cell and note the plus (+) and minus (-) markings used to identify the ends. Your teacher will take a cell to pieces for you to help you understand the importance of these signs. Would you agree that in future experiments it will be important to record the way in which cells are connected into a circuit?

5.12 Magnetic Fields

Apparatus Required

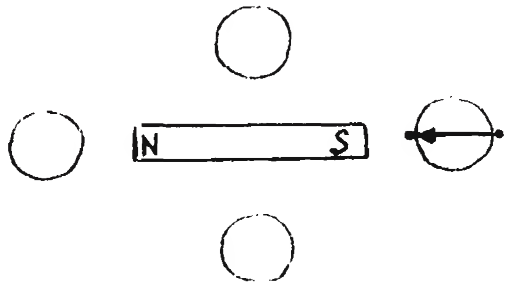


Qu	Apparatus	Item No.
1	Dry Cell Holder with Cells	5.10/01
1	Bulb Holder with Bulb	5.10/02
1	Switch	5.10/03
1	Multipurpose Coil with Cores	5.10/04
12	Compass	5.10/05
2	Cylindrical Magnets	5.10/06
1	Tangent Galvanometer	5.10/07
2	Soft Steel Wires (Paper clips straightened out and cut to 3 cms long)	
	Connecting Leads	

Activities

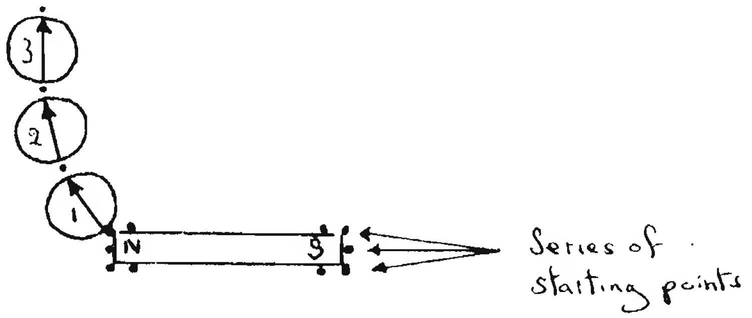
You will probably have already noted that a current carrying coil (or magnetized core) can exert an attractive force on pieces of iron and steel (including pivoted magnetic needles) without actually touching such items. The magnetic influence of a current carrying coil (or magnetized core) would seem to extend beyond its own boundaries into the area surrounding it. The following experiments are all designed to invesitgate such areas.

(i) Place the cylindrical magnet provided on the center of a sheet of paper, and outline its position. (A small piece of modelling clay between the magnet and paper will prevent it from rolling about). Indicate on the outline the North and South Poles of the magnet. Make sure that there are no iron or steel objects lying on the table, apart from the magnet provided. Place the compass two to three centimeters away from first one end of the magnet and then the other, noting the direction in which the needle points. This can be recorded by marking dots on the paper to represent the end of the needle. An arrow joining the two dots will represent the direction of the needle, with the arrow head corresponding to its North Pole. Repeat the observations with the compass two

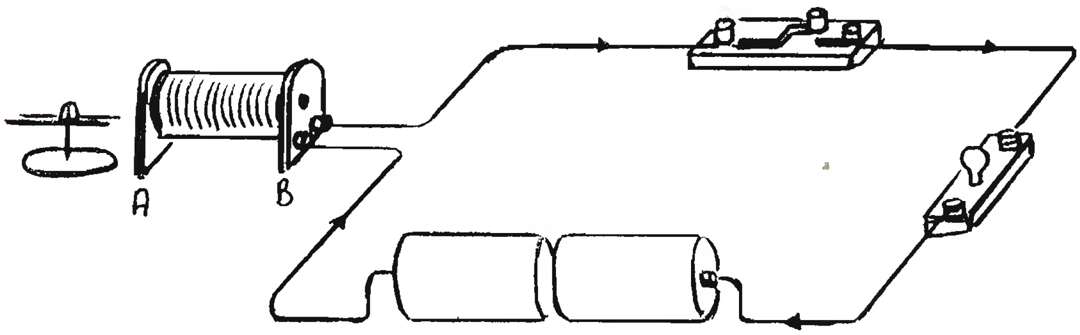


to three centimeters from either side of the magnet. Is the compass needle affected in these positions? We generally refer to an area which is under the influence of a magnet as the magnetic field of the magnet, and we say that the direction of the magnetic field at any point is the direction in which the compass needle points.

You should now find it possible to record the whole magnetic field around the magnet by such a technique. Place the compass next to one end of the magnet and record its direction (position 1). Then move it to a second position (2) so that the tail of the needle lies above the dot, representing the North Pole of the needle in the first position (1). Repeat this process over and over again for subsequent positions until the resultant line either returns to the magnet or reaches the edge of the paper. Then repeat the whole process starting from a new point at the end of the magnet. It should be possible to create 5 or 6 distinct lines in this way, indicating continuously the field of the magnet.



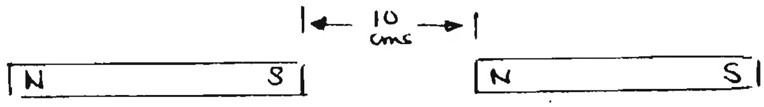
(ii) Connect the multipurpose coil into a circuit with two dry cells, a bulb and a switch. Place the compass at either end of the coil and along either side to determine whether the current carrying coil has the same type of magnetic field as the cylindrical magnet. What do you conclude?



Draw a diagram of your circuit, and indicate the direction of the current around the circuit by arrows showing a flow towards the carbon rod of the cell. Draw a representative diagram of the coil as viewed from either end.

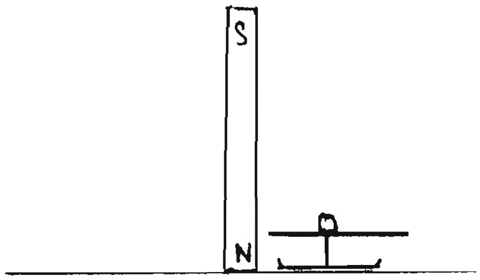
You should be able to indicate the direction of the current on each diagram, and whether the magnetic behavior observed at that end of the coil corresponds to that of a North Pole or a South Pole.

(iii) Take two cylindrical magnets and lay them on the same line on a piece of paper so that their ends are about 10 cms apart, and the North Pole



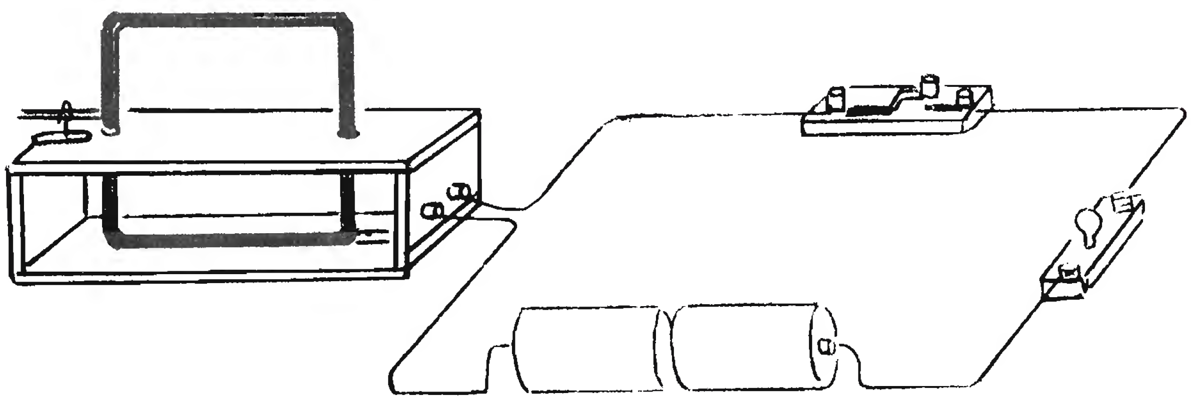
of one magnet points towards the South Pole of the other. Take your compass and plot the magnetic field in the gap between the opposing magnetic poles.

Reverse the direction of one of the magnets so that two like poles face one another across the gap, and once more plot the field. Finally, stand one magnet on its end, away from other magnets, and plot the field around the end of the magnet in contact with the paper.



(iv) In view of the observations to date it would appear logical to hypothesize that a single current carrying conductor should produce its own magnetic field. However, the field around a single conductor is likely to be very weak, and might be detected more readily if strengthened by identical conductors lying side by side. It is suggested that you try to detect such a field, and for this purpose you are provided with a vertical coil (a tangent galvanometer). This contains a rectangular coil held in a vertical plane, and each of the sides of the coil might be considered on its own as a straight conductor. Since the coil contains 60 turns of wire, any magnetic field produced around the conductors should be well magnified.

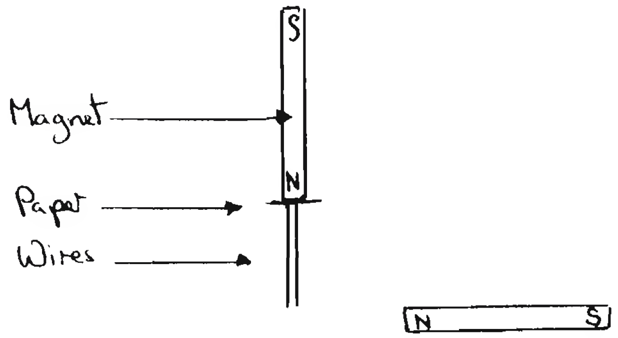
Connect the vertical coil into a circuit in series with two dry cells, a switch and a bulb. Place a compass on the platform close to one



of the sides of the coil. Switch on the current and note the direction of the magnetic field. Move the compass to different positions on the platform, but still in contact with the side of the coil, and hence determine the direction of the magnetic field at all points around the side. In recording your results indicate on your diagram both the direction of the magnetic field around the side of the coil and the related direction of the current in the side of the coil.

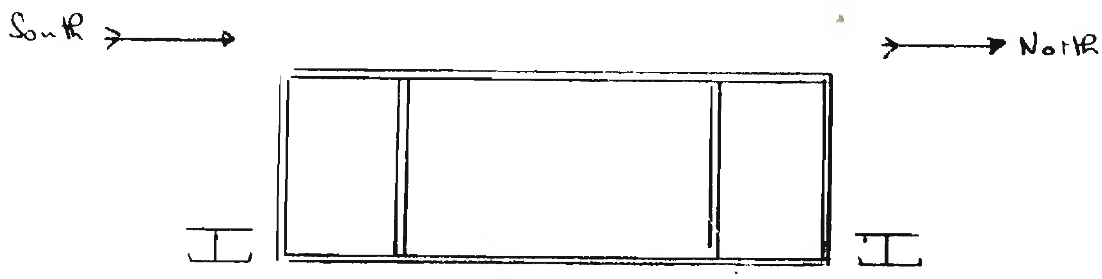
Make an identical set of observations on the other side of the coil. Finally reverse the current in the circuit and compare your results.

(v) You are provided with two cylindrical magnets and two steel wires. Attach the two wires to the end of the magnet so that they hang downwards from the North Pole. Do the two wires remain parallel to one another, and in contact? What happens to the wires if you bring the North Pole of the second magnet close to the free ends of the wire? Do the wires behave in the same way if the South Pole of the second magnet is brought near to the free ends of the wire?



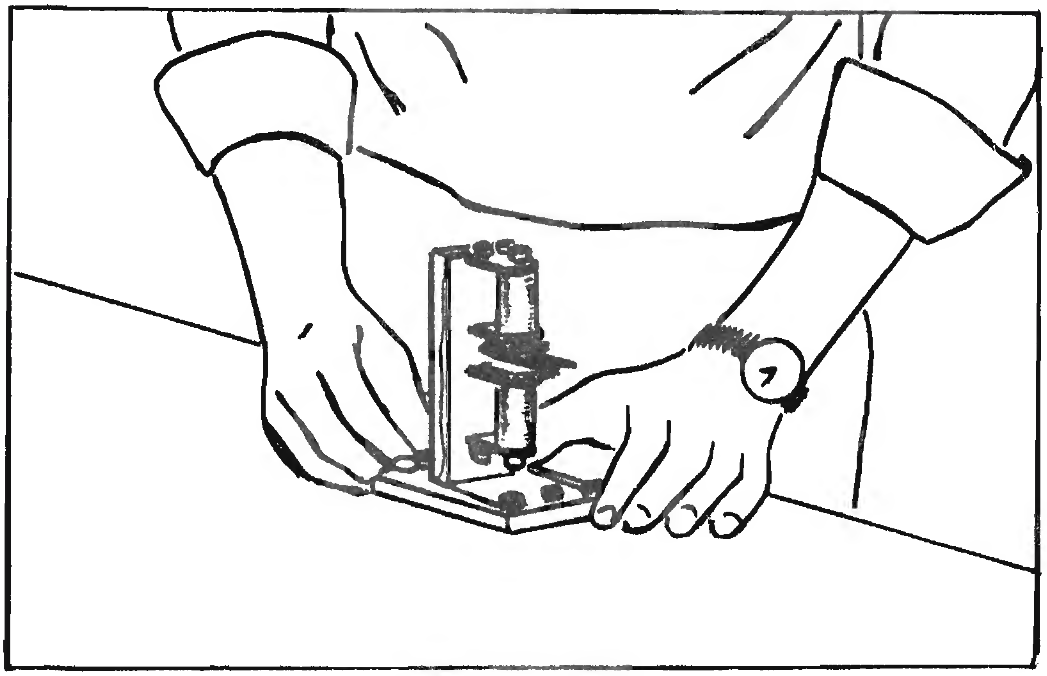
Try repeating the experiment with a very small piece of paper between the wires and the magnet from which they are suspended. Do you observe the same pattern of behavior? Can you explain this?

Now look around your classroom for any long piece of iron or steel that is permanently fixed in a North-South direction. A steel framed window is ideal for this purpose. Take your compass needle and hold it close to the North and then the South end of the window. Does the needle indicate the existence of magnetism in the window frame? If so, at which end of the window did you find a magnetic North Pole?

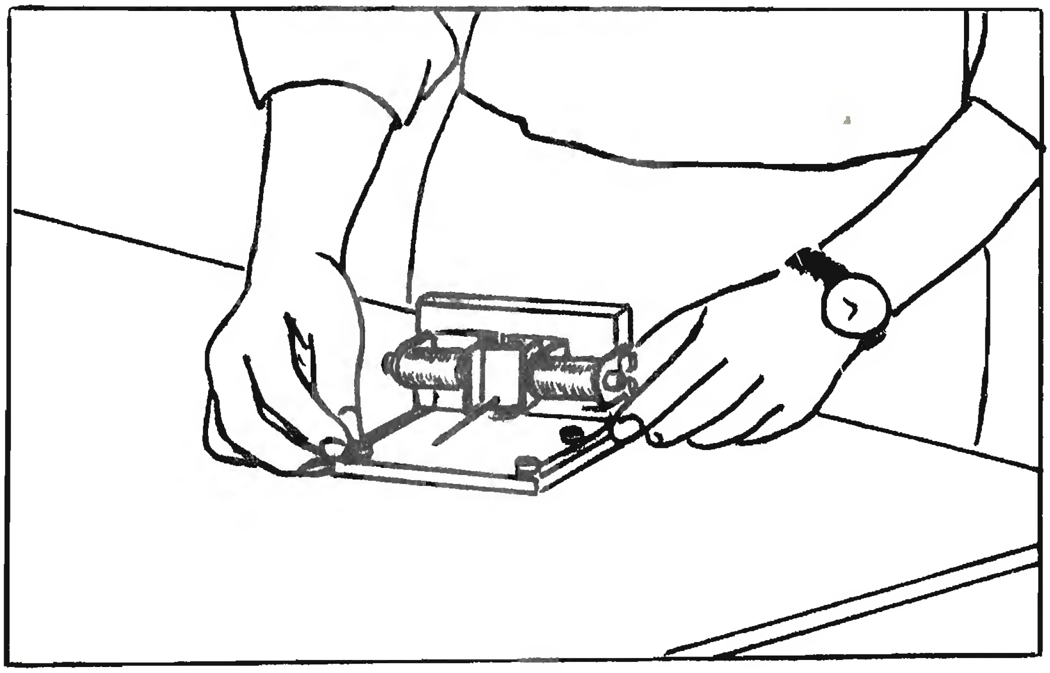


5.13 Forces on Current Carrying Conductors

Apparatus Required

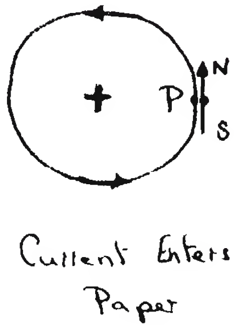


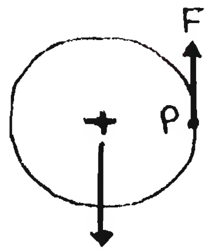
Qu	Apparatus	Item No.
2	Dry Cell Holders with Cells	5.10/01
2	Bulb Holders with Bulbs	5.10/02
2	Switches with Connecting Leads	5.10/03
1	Magnetic Field Apparatus	5.10/08-09
1	Moving Coil Galvanometer	5.10/10-11-12
1	Dynamo/Motor	2.70/01-02



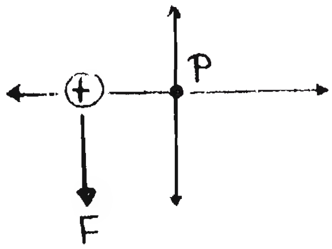
Activities

(i) We have already seen that a current can create a magnetic field, capable of exerting forces on a magnetic needle in such a way that the North Pole of the needle moves in the direction of the field, and the South Pole in the opposite direction. If we could isolate a North Pole



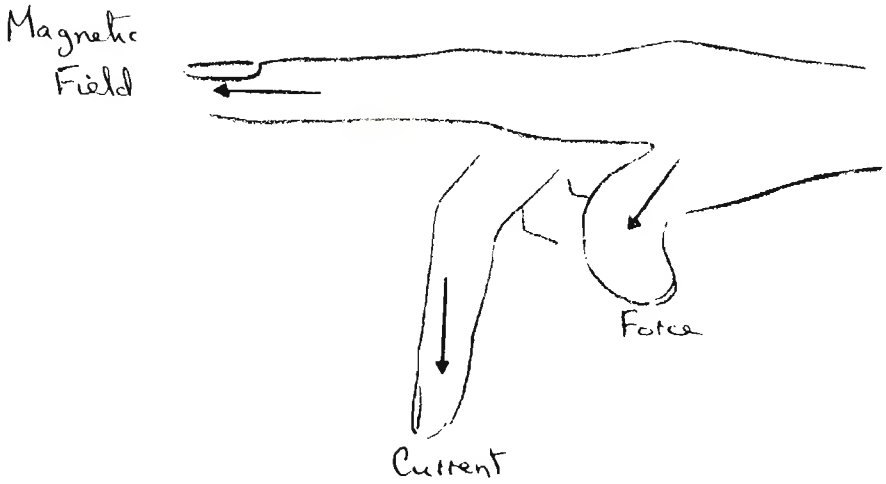


and place it in the magnetic field at a point P it would follow that this would be subjected to a force (F) which would attempt to drive the pole in an anticlockwise direction around the conductor. We might theorize that since it is the current carrying conductor that exerts the force on the North Pole at P, that the North Pole would exert an equal and opposite reaction on the conductor.

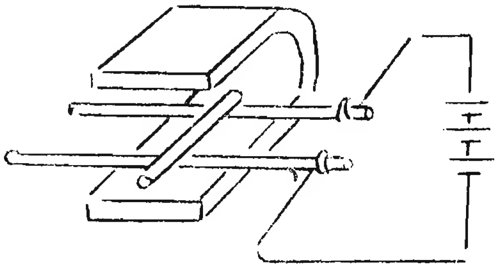


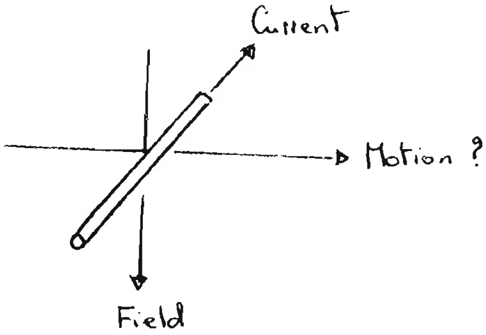
It is useful to review our theory as follows. If a North Pole is isolated at P it would produce a radial magnetic field. This field would cut across the current carrying conductor (+), and we have theorized that a force (F) would be exerted on that conductor. The resultant three dimensional picture might be put over better by spreading out the thumb and first two fingers of the right hand so that all three are at right

angles, and marking them force, field and current as indicated in the diagram.

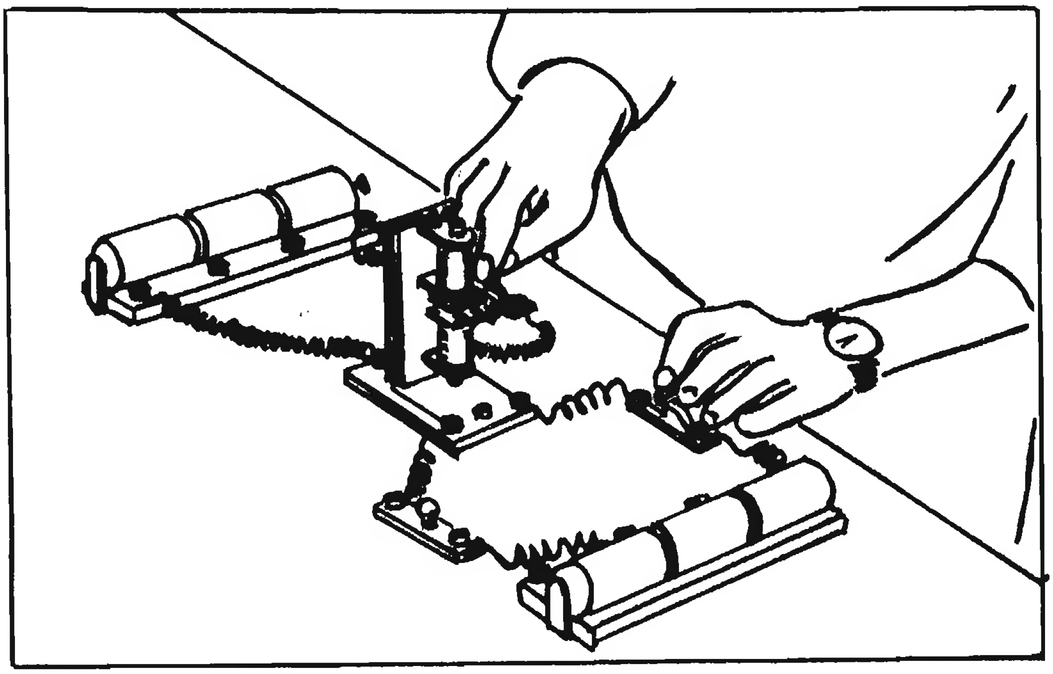


Now let's test out the theory to see whether a magnetic field can exert a force on a current carrying conductor, and if so whether the direction of the force is according to the rule we have worked out. All we need to do is create a strong magnetic field, and place a current carrying conductor on rails set at right angles to the field, so that if a force is exerted on the conductor the latter will roll along the rails.



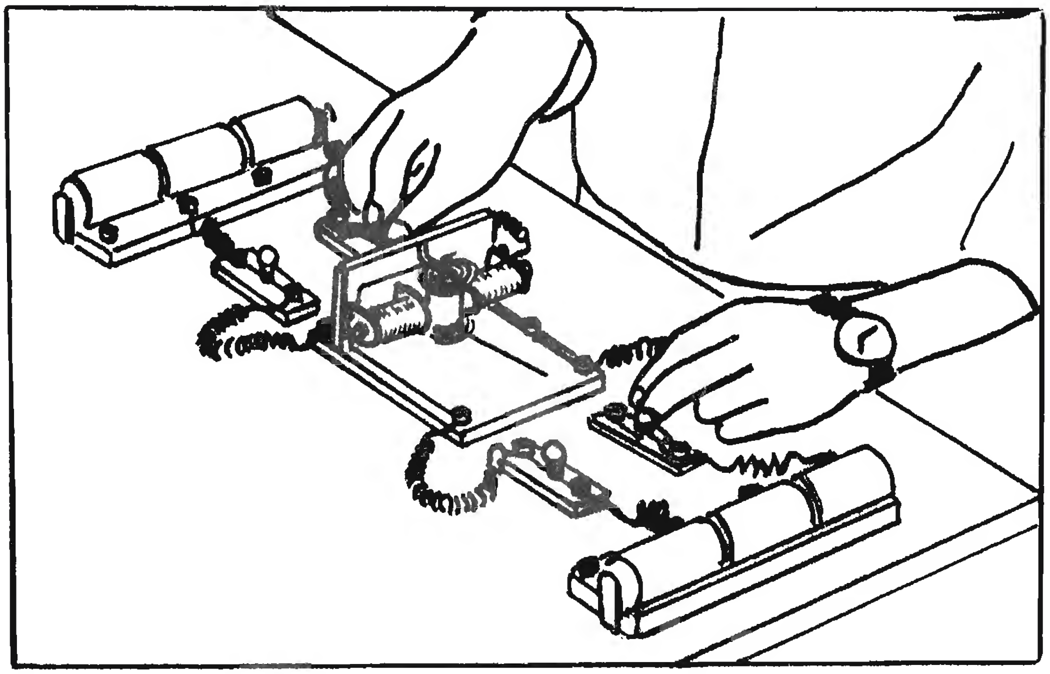


Take the magnetic field apparatus and adjust the levelling screw on the base to insure that the rails are perfectly horizontal and the conductor, given a slight tap, will roll just as easily in one direction as the other. Then clean the rails and rolling conductor with sandpaper to insure good electrical contact. Create the magnetic field, at right angles to the conductor, by connecting two multipurpose coils into a circuit with 2 dry cells, a bulb and a switch.



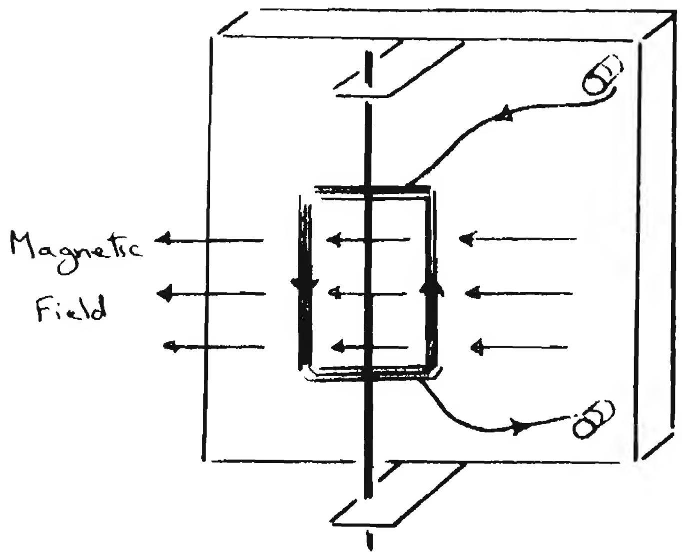
Connect the horizontal rails into a circuit containing 3 dry cells and a switch. Place the rolling conductor on the horizontal rails between the pole heads of the multipurpose coils, and switch on the two circuits briefly (particularly brief since the rolling conductor circuit contains no bulb). Does the conductor move along the rails, and if so in what direction?

(ii) You are provided with a moving coil galvanometer which is basically a rectangular coil pivoted on a vertical axis and subject to the influence of a magnetic field. In this case the magnetic field is created by two multipurpose coils connected into a circuit with 2 dry cells, a bulb and a switch. The current through the coil is created by



connecting the coil into an identical circuit.

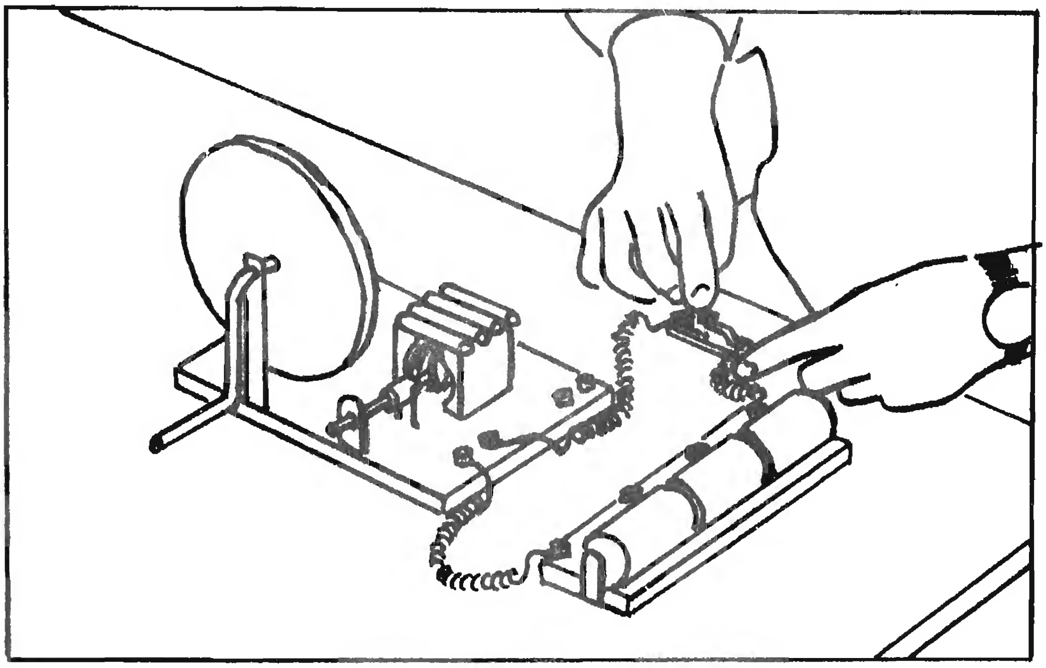
Connect the moving coil galvanometer into the circuits as indicated above, but do not switch on yet. Study the circuits and determine the direction of the current through the rectangular coil, and the direction of the magnetic field cutting the coil. Make a rough diagram similar to the one which follows to indicate the relationship you have determined between the magnetic field and current, and use your knowledge to date to predict the way in which you anticipate the coil to rotate.



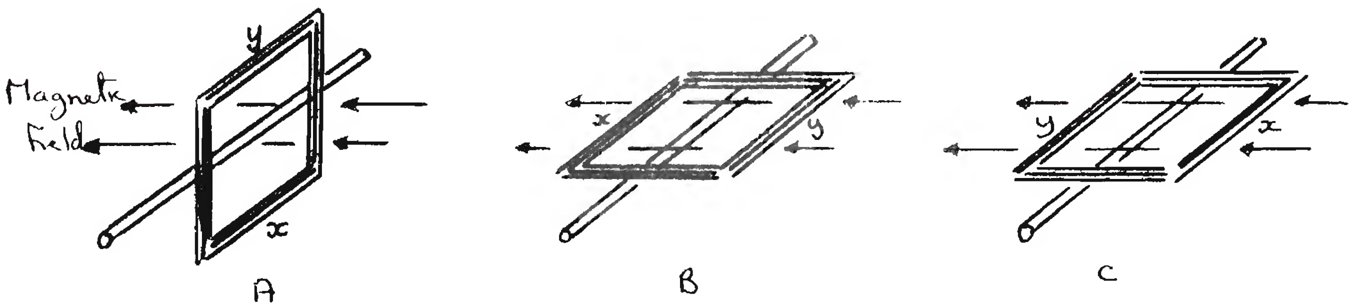
Switch on the two circuits. Does the coil rotate in the direction predicted? What is the purpose of the delicate spring attached to the coil?

(iii) At this point the teacher will bring out an electric motor which you have already seen in studying energy conversion from one form to another. For use on this occasion the driving wheel is disconnected from the armature axle, since the intention is to see how a current drives the motor, rather than to see how mechanical motion of the armature creates a current.

The motor is basically a rectangular coil lying in a strong magnetic field, in much the same way as the coil just observed with the moving coil galvanometer except that the motor coil has no spiral springs at either end. There are two pairs of terminals by which the motor coil can be connected into a circuit, one pair marked AC and the other DC. Connect the coil into a circuit with 3 dry cells and a switch by means of the AC terminals.



Rotate the coil until it lies in a vertical plane (A), and switch on the current. Does the coil rotate? Turn the coil forward through 90° until it lies in a horizontal plane (B), and once more pass a current, noting the direction in which the coil moves. When it stops move it a further 90° forward in the direction in which it has just rotated so that it once more lies in a horizontal plane (C), but 180° beyond the first horizontal position (A). On switching on the current does the coil rotate in the same direction as before? Is this as you would expect from the theory?

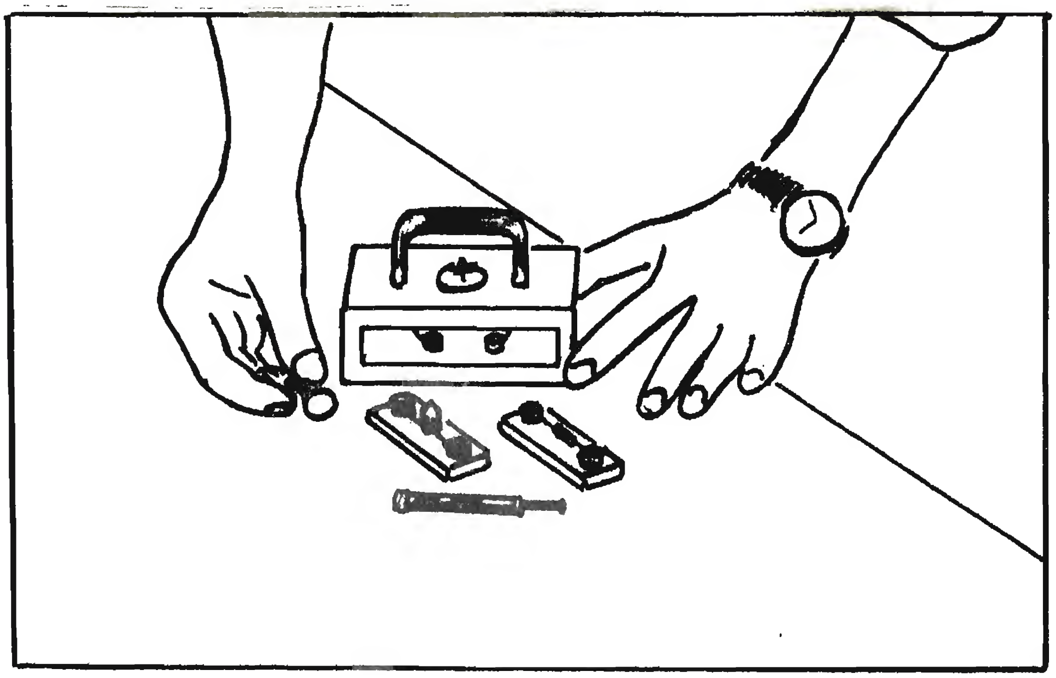


Now connect the coil to the dry cells and switch by means of the terminals marked DC. As before see if the coil can be made to rotate when it is first of all in a vertical plane, and then in a horizontal plane. What happens? Take a close look at the rings and contacts by which current passes from the cells to the coil when the DC terminals are used. Are they effectively the same as those involved when the AC terminals are used? Can this explain the different behaviors of the coils?

5.20 DETECTION AND PRODUCTION OF ELECTRICITY

5.21 Detection of Electricity

Apparatus Required

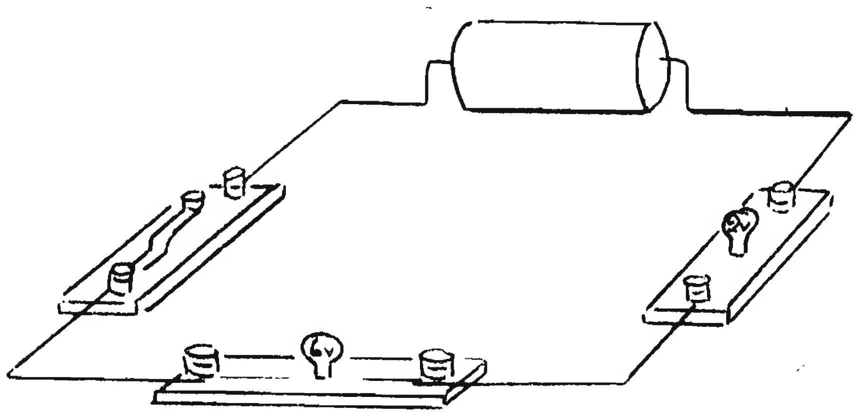


Qu	Apparatus	Item No.
2	Dry Cell Holder with Cells	5.10/01
4	Bulb Holder with Bulbs (2.5 volts, 0.3 amps)	5.10/02
1	Bulb (6.2 volts, 0.3 amps)	
2	Switches	5.10/03
1	Neon Bulb Holder with Bulb	5.20/01
1	Electricity Tester	5.20/02
1	Tangent Galvanometer	5.10/07
1	Resistor Holder with Resistor	5.20/03
1	Moving Coil Galvanometer	5.10/10-11-12
	Connecting Leads	

Activities

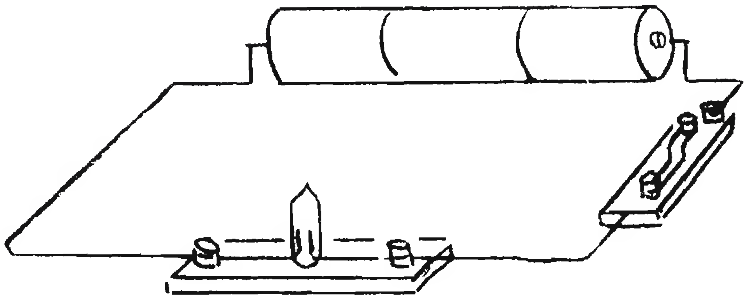
In order to learn more about electricity it is important not only to know how to produce it, but also how to detect it once it is created, and this shall be our immediate concern.

(i) So far we have used the lighting effect of a bulb to recognize the existence of electricity in a circuit, and it is worthwhile looking at this a little more closely. Will a bulb always indicate the presence of electricity by lighting up? To answer this question, set up a circuit in the usual way with a dry cell, switch and two bulbs, one small (2.5 volts, 0.3 amps) and one large (6.2 volts, 0.3 amps). Which of the two bulbs lights up when the circuit is completed?

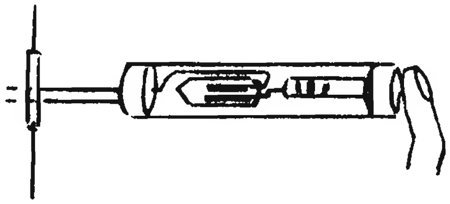


Repeat the experiment with 2 cells and then 3 cells in the circuit. Do both bulbs detect the presence of electricity equally well? Is it possible for electricity to exist in the circuit without being detected by one of the bulbs? Look closely at the two bulbs. Can you see any difference between them, apart from the size of the bulb?

(ii) Connect the neon bulb into a circuit with 3 dry cells and a switch. Does it light up when the switch is pressed? What is the main difference between the neon bulb and the bulbs used in previous experiments?

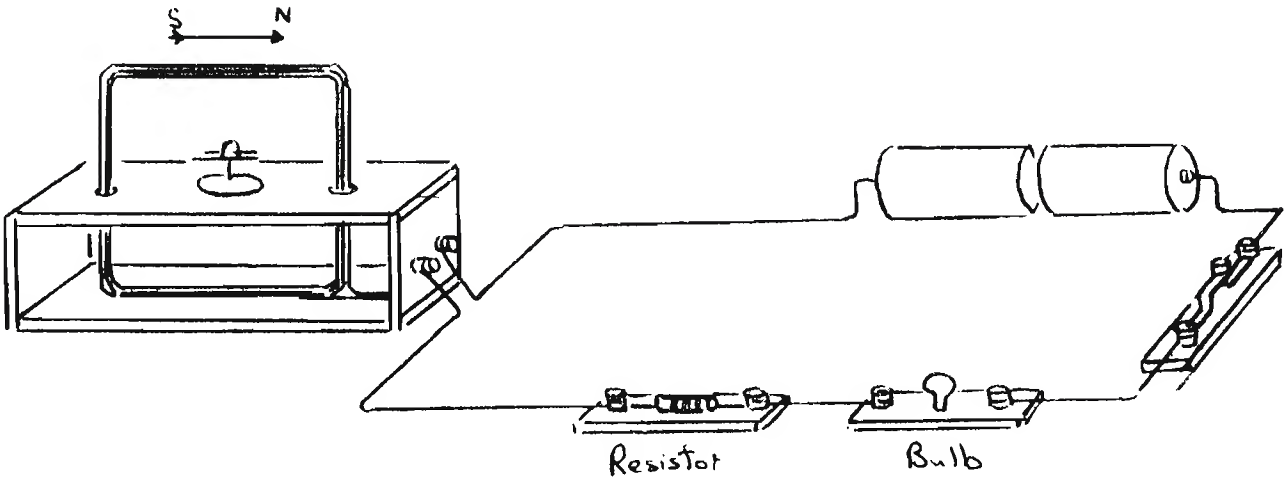


The electricity tester provided contains a neon bulb and a resistor as a safety device. Make sure that your hands and shoes are dry and then press the probe of the tester into the mains socket, keeping your fingers well away from the inserted metal. Place your finger on the rear end of the tester, and then remove it. What happens?



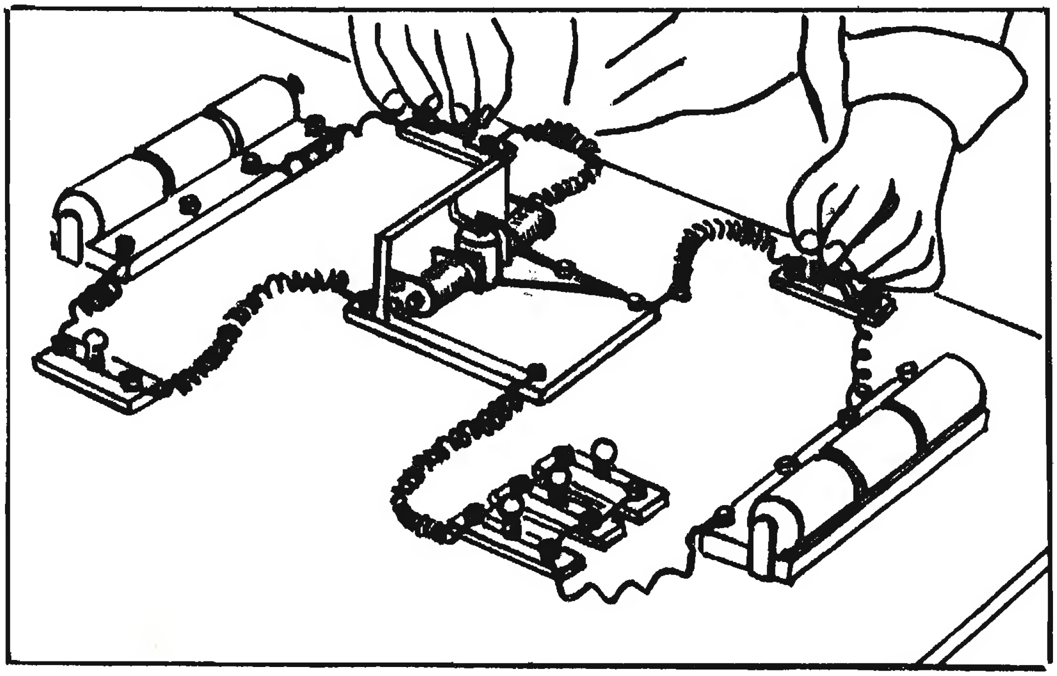
(iii) Set up the tangent galvanometer on the table so that the plane of the coil lies in a North/South direction. Then connect the galvanometer into a circuit with a dry cell, a bulb and a switch. Switch on the current briefly. Now add a 50 ohm resistor to the circuit. Does the bulb still

light up? Is there any indication that a current is able to pass through the resistor? Repeat the experiment with two dry cells in the circuit.

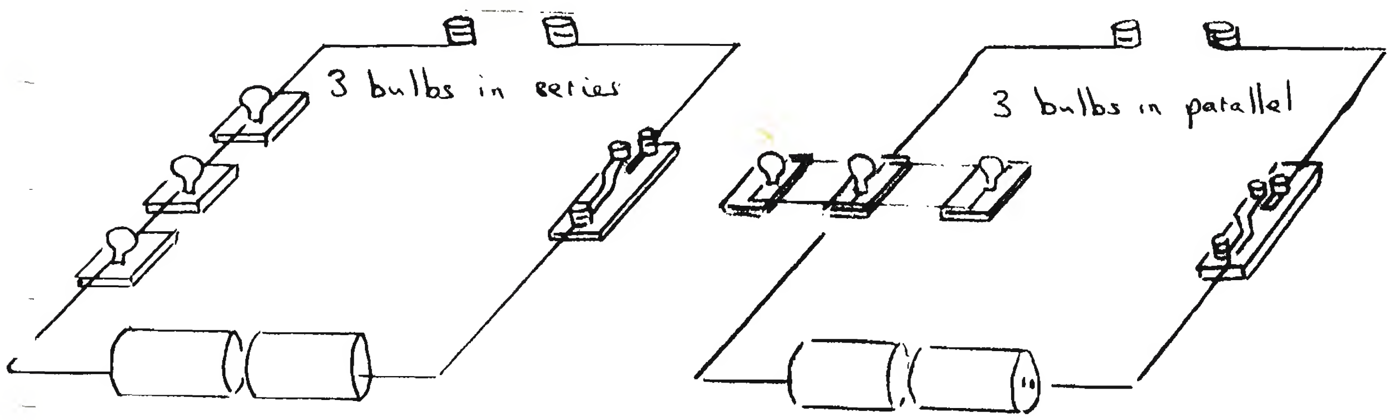


(iv) Take the moving coil galvanometer and connect the multipurpose coils to a circuit containing 2 dry cells, 1 bulb and a switch, thus providing the galvanometer with a magnetic field across its moving coil.

Connect the moving coil of the galvanometer to a circuit containing 2 dry cells, 1 bulb and a switch. Switch on both circuits and note the deflection of the galvanometer. Repeat the experiment with 2 bulbs and then 3 bulbs in series with the moving coil. What effect does increasing the number of bulbs have on the current in the circuit? Can you explain?

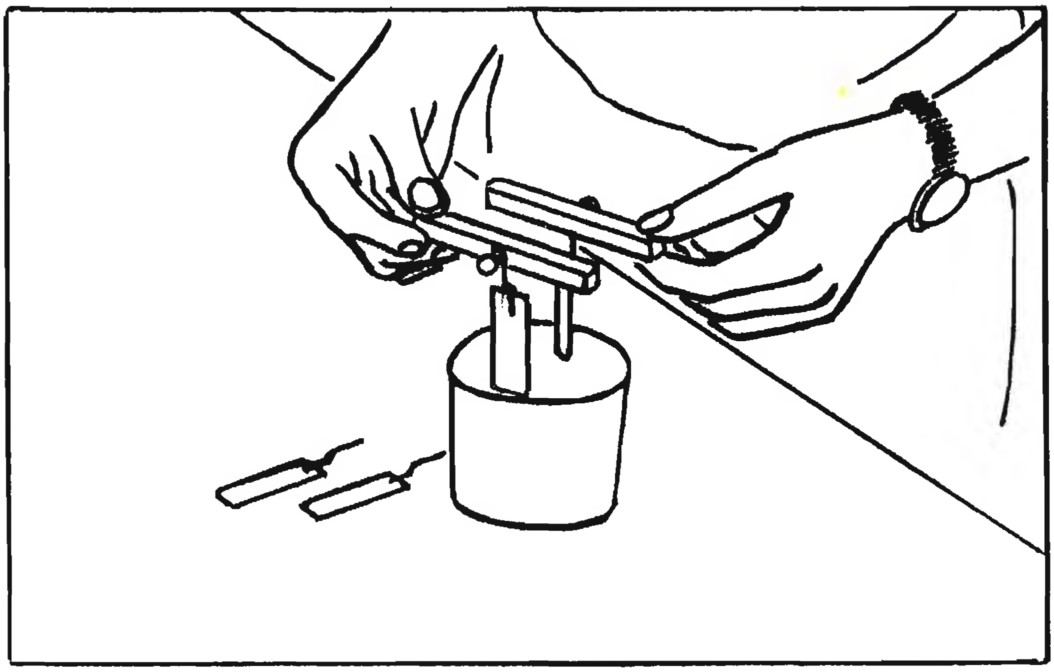


So far you have added bulbs to the circuit in series with one another. Now repeat the experiment with 1, 2 and then 3 bulbs added in parallel into the circuit with the moving coil. Note the deflection in each instance. Can you explain the new pattern of behavior?



5.22 Production of Electricity

Apparatus Required

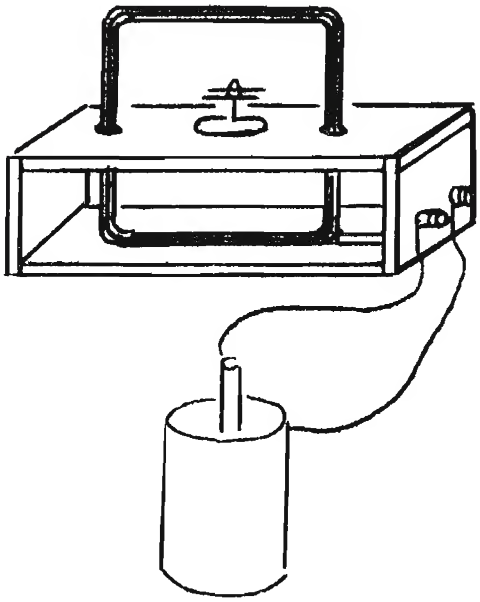


Qu	Apparatus	Item No.
1	Dry Cell Holder with Cell	5.10/01
1	Bulb Holder with Bulb	5.10/02
1	Switch	5.10/03
2	Multipurpose Coils	5.10/04
1	Cylindrical Magnet	5.10/06
1	Soft Iron Core (Nail 10 cms long, 0.7 cms diameter)	
1	Tangent Galvanometer	5.10/07
1	Dynamo/Motor	2.70/01-02
1	Chemical Cell	5.20/04
	Vinegar	
	Salt	
	Connecting Leads	

Activities

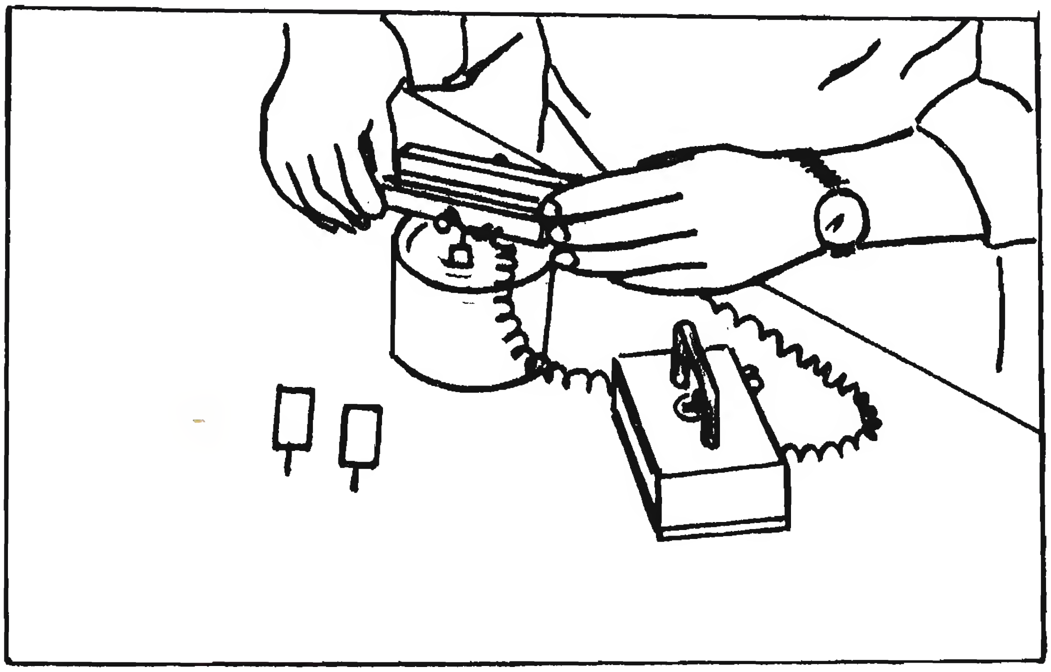
(i) So far we have used dry cells to produce electricity, and we should ask ourselves whether the metals and chemicals used in a dry cell are unique in producing electricity, or whether other metals and chemicals could perform in the same way.

Remove the dark substance (ammonium chloride) from the inside of an old dry cell, so that only the zinc case and carbon rod remain. Then connect the cell to the tangent galvanometer placed with the plane of its coil in a North/South direction. Hold the carbon rod inside the case, but not touching it. Now fill the case with water. Does the galvanometer indicate the existence of a current? Add salt to the water. What happens? Replace the salt water by vinegar (acetic acid). Does the cell now produce a current?



(ii) It is theoretically possible to repeat the foregoing experiment with different types of rods and cases, but in reality it is not too easy to find a series of cases identical in size to the zinc case, but made of different materials. However, precisely the same type of observations may be made with the help of the chemical cell in which we replace the zinc case by a zinc plate. The zinc plate and carbon rod may thus be immersed in different solutions (contained in a plastic container), and readily replaced by plates of different materials.

Fill the plastic container of the chemical cell with vinegar. Clean the zinc plate with emery paper and then lower both it and the carbon rod into the vinegar so that they are parallel to one another and about 0.5 cms apart. Connect the plate and cell to the tangent galvanometer. Does the galvanometer indicate the production of electricity by the cell?



Replace the carbon rod by an iron plate, and make sure that both iron and zinc plates are cleaned with emery paper before reimmersing in the vinegar. Note the deflection produced immediately after the immersion of the plates in the solution. Does this remain constant? With the plates parallel to one another, and almost touching, note the deflection of the galvanometer. Then keeping the plates parallel to one another move them as far apart as possible in the solution. What does the galvanometer indicate? Bring the plates close to one another again. What happens when the plates actually touch each other? With the plates close together raise them slowly out of the solution, and then equally slowly reimmerse them. You might repeat this observation raising only one of the plates from the solution. What conclusions can you make?

It is now proposed that you compare the effectiveness of different plate combinations immersed in vinegar. In each instance completely immerse the plates and hold them so that they are always 0.5 cms apart. Record the initial deflection of the glavanometer in each instance. The combinations proposed for comparison are zinc and carbon, zinc and iron, zinc and copper, iron and copper, iron and carbon, and carbon and copper.

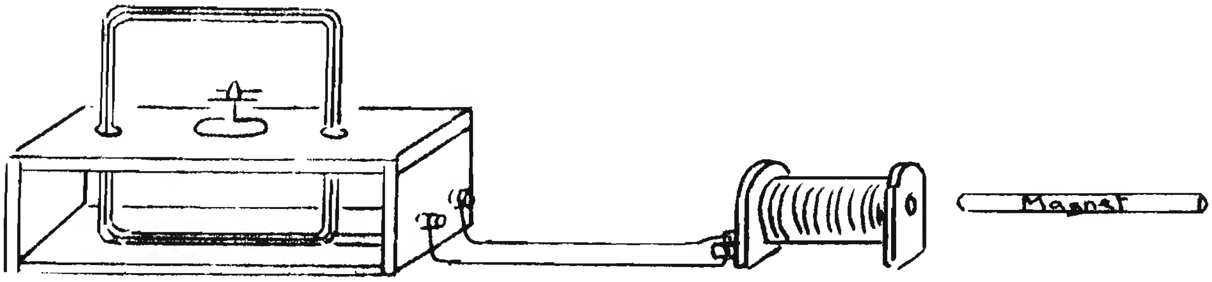
You might like to repeat one or two of the combinations in saturated salt solution. Tabulate your results.

(iii) We have already seen that whenever a current is created in a conductor a magnetic field automatically results. Is it possible that the reverse might happen? In other words could the creation of a magnetic field around a conductor produce an electric current in it?

In this experiment a magnet is to be used as well as a tangent galvanometer. A simple precaution is therefore necessary. You will note that if the magnet is placed close to the galvanometer the needle will be affected, and any rapid movement of the magnet will be detected by the galvanometer. Move the magnet away from the galvanometer, and record the minimum separation required between the two such that any rapid movement of the magnet will not be detected by the galvanometer.

Now join the tangent galvanometer and multipurpose coil into a simple circuit, making sure that the multipurpose coil is separated from the galvanometer by a distance exceeding the minimum just determined, for the magnet will be used in the vicinity of the coil, and it is important to know that any deflection of the galvanometer needle is not caused by the ordinary movement of the magnet.

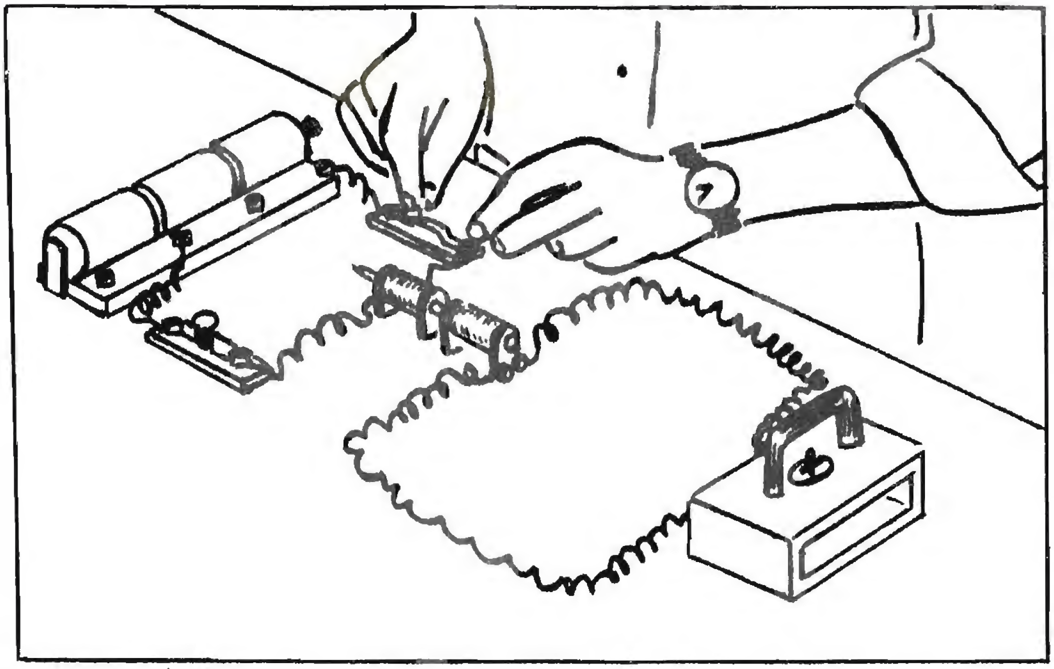
Once the circuit has been set up, place the magnet inside the coil, creating a magnetic field where none existed before, and then note whether the galvanometer indicates the existence of a current in the circuit.



Keeping your eye on the galvanometer remove the magnet as rapidly as possible from the coil. Do you notice anything unusual while you are doing this? Place the end of the magnet a fraction of a centimeter inside the coil, and then slide it rapidly back inside. Does this motion have any effect on the galvanometer? Once more remove the magnet from the coil, but somewhat more slowly. Are the effects you have observed affected by the speed with which the magnet moves in and out of the coil?

(iv) Set up the tangent galvanometer and multipurpose coil in a circuit in exactly the same way as for the above activity. Then make a second (electromagnet) circuit with 2 dry cells, a bulb, a switch and another multipurpose coil. Place the two multipurpose coils end to end

and insert the same soft iron core along the axis of both coils.

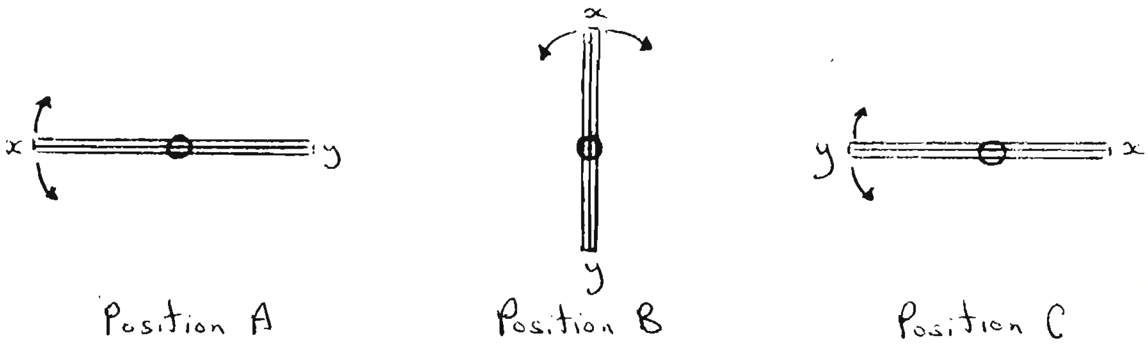


Carefully observing the galvanometer, record what happens when the current is switched on in the electromagnet circuit. Let the galvanometer needle settle down, and then note its behavior when the current is switched off. (It is worthwhile repeating the experiment without the bulb in the electromagnet circuit, thus producing a stronger magnetic field. However, avoid switching on the circuit for too long a period of time, thus ruining the cells).

(v) If the motion of a magnetic field cutting a stationary conductor (in this case a coil) can produce a current, we might theorize that the motion of a conductor through a stationary magnetic field should also produce a current in a conductor. This idea is best studied with the help of the dynamo.

Connect the dynamo coil to the tangent galvanometer, by the AC terminals, making sure the galvanometer is far enough away not to be affected by the magnets surrounding the coil. Then with the coil in a horizontal plane (A) rotate it sharply forward through about 45°, noting any deflection of the galvanometer. When the pointer settles down rotate the coil sharply back-

wards through 45° from the same horizontal position. Does the galvanometer indicate that the direction of the current through the galvanometer varies with the direction in which the coil is rotated?



Place the coil in a vertical position (B). Allow the galvanometer needle to settle down, and then repeat the observations rotating the coil sharply backwards and then forwards through about 45°. Is the current produced in this position as large as in the horizontal position?

Return the coil to its original horizontal position (A) and note the direction of the deflection when the coil is rotated sharply forward (clockwise). Then rotate the coil forward through 180° so that it once more lies in a horizontal position (C). Once more rotate the coil forward sharply. Does the galvanometer indicate the current flowing through it as being in the same direction as when the dynamo coil was in the first horizontal position (A)?

Now, connect the tangent galvanometer to the DC terminals, and repeat the above observations. Record any differences in behavior compared with the foregoing experiment using AC terminals.

Finally, connect a small bulb (2.5 volts, 0.3 amps) to the dynamo, first using the DC terminals and then the AC terminals. Is it possible to light the bulb by rotating the dynamo armature in both cases?